BONUS! Guide to the Night Sky 2013

COMET ISON
WILL IT BE A SUPERSTAR? p. 57

HOW VOYAGER
CHANGED THE SOLAR SYSTEM p. 30

JANUARY 2013

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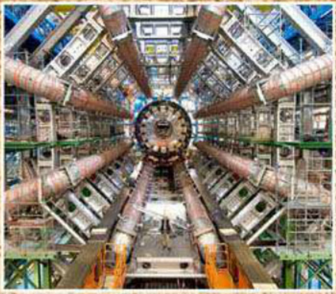
TOP 10

ANNUAL SPECIAL ISSUE

SPACE STORIES OF THE YEAR

- Higgs boson detected
- Curiosity explores Mars
- SpaceX visits Space Station
- Surprising exoplanets found
- Exploding stars deciphered

AND MORE p. 22



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THE WEIRD SCIENCE OF GRAVITATIONAL LENSING p. 44

Vol. 41 · Issue 1


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FROM THE **EDITOR**

BY DAVID J. EICHER

Astronomy's 40th anniversary year

Astronomy enthusiast Steve Walther, a Wisconsinite and recent college graduate, founded *Astronomy* magazine May 27, 1973. Less than 10 years later, the magazine had grown to become the largest on the subject in the world, an honor it still holds. To celebrate the start of our magazine's 40th anniversary year, our talented staff is unveiling a redesigned magazine this month.

You'll see some updates with small things here and there — the way typography is used, the opening looks of the hobby features on observing, imaging, and telescopes. But you'll notice the redesign most at the front of the magazine, in what publishing professionals call the FOB — the "front of the book." Inspired by several cutting-edge magazines, I proposed to Art Director LuAnn Williams Belter and her team a new look that would incorporate the news, columns, and letters with an environment that would be richer and more fun to explore. (See early mockup below.)

You'll note more diagrams in the Astro News section, as well as some other graphics and factoids that are engaging and information-rich. The layout also incorporates a couple of new pages, "Breakthrough" and "Final Frontier," that will share new astrophysics-related photos, with explanations of what's happening in the pictures. The whole FOB is now termed "Quantum Gravity," a nice-sounding phrase that leans toward the day when all of our knowledge will combine into one understanding of astrophysics and cosmology.

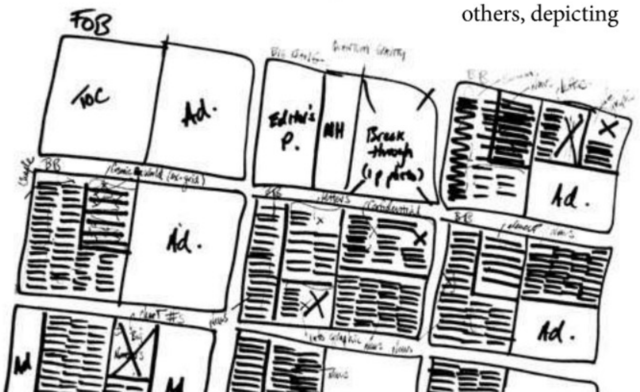
Needless to say, I hope you like the magazine's new, more engaging look. Also as part of the redesign, I will be discontinuing my "Deep-sky Showcase" column, a page I've written for the past three years. In its place, we are debuting a new column, "Astro Sketching," written by the accomplished amateur astronomer Erika Rix of Liberty Hill, Texas.

Rix is a wonderfully talented artist whose eyepiece drawings of astronomical objects preserve memories of great nights out under the stars. Her column will feature her own sketches and those of others, depicting both solar system and deep-sky objects.

Her dedication to sharing observing and sketching techniques is a key part of Rix's interest in astronomy outreach. She wrote a tutorial for Christian Legrand and Patrick Chevalley's *Virtual Moon Atlas* software and eventually co-authored two sketching books: *Astronomical Sketching: A Step-by-Step Introduction* (Springer-Verlag, 2007) and *Sketching the Moon: An Astronomical Artist's Guide* (Springer-Verlag, 2011).

Rix and her husband, Paul, recently moved to the Austin area, where they now enjoy a warm climate with a more southern latitude. She is a member of the Austin Astronomical Society and volunteers at outreach events as well as serves as the club's newsletter editor. Please join me in welcoming Rix to our family!

And lastly, you'll see some new icons in the magazine. We are initiating a service by which we'll offer instantly downloadable PDF packages of stories that relate to some of our feature articles. Look for them — they will offer, for a small price, a huge amount of knowledge and insights on the hobby and science of astronomy.



Yours truly,

David J. Eicher
Editor

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ON THE COVER

The newest Mars rover is just one of this past year's top space stories, which span topics from exploding stars to funding to exoplanets.

FEATURES

COLUMNS

QUANTUM GRAVITY

IN EVERY ISSUE

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The inside scoop from the editor

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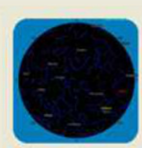

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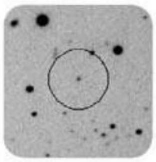
EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH . . .

HOT BYTES >>

TRENDING TO THE TOP



COMET ISON C/2012 S1
By November 2013, this fuzzball may be the brightest comet anyone now alive has ever seen; we can hope!

ROCKS ON MARS
NASA's Curiosity rover begins exploring in earnest, examining rocks like "Jake Matijevic," a pyramidal stone with interesting features.

COMET PANSTARRS C/2011 L4
Overshadowed by ISON, PANSTARRS will itself be quite bright, reaching 2nd magnitude or better by March 2013.

SNAPSHOT

Civilizations in the universe

We know roughly how many stars and how many galaxies lie in the cosmos. What about life? Intelligence? Advanced civilizations?

Astronomers are finding more and more extrasolar planets. On Earth, the only host for life we know in the cosmos, we find microbes that survive eons frozen in ice and also thrive in the most hostile environments imaginable.

Now consider the galaxy M83. This barred spiral in Hydra bears a resemblance to our Milky Way. It is smaller, only 40,000 light-years across, but the structure is very much the same.

We know the Milky Way holds approximately 400 billion stars. Our Sun is but one of these. We also know the universe has at least 125 billion galaxies.

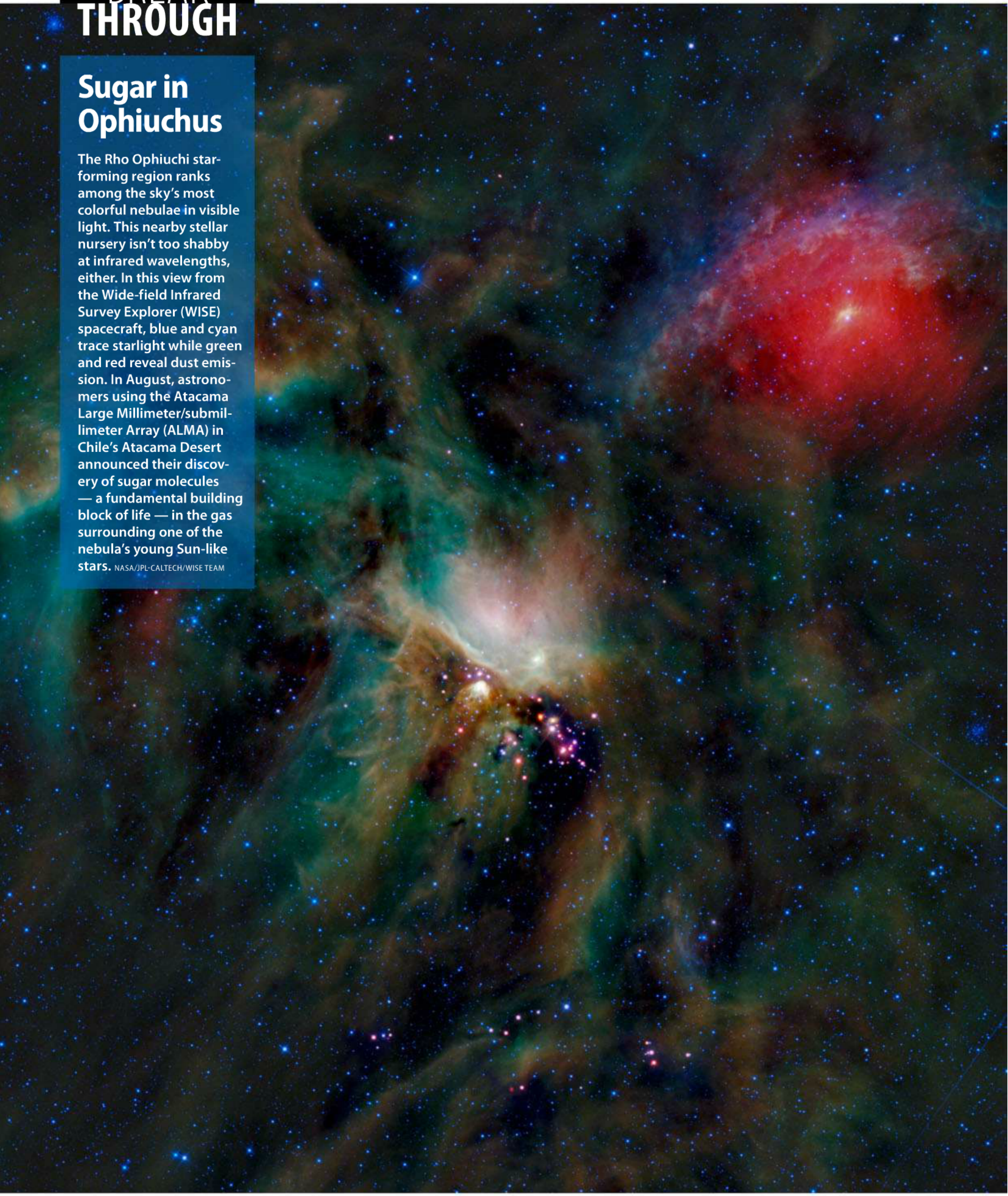
So the cosmos probably holds a minimum of around 50,000 billion billion stars. How many planets in our galaxy, dare we say in the universe, have life? Intelligent life? Civilizations?

Let me know what you think at editor@astronomy.com. I'm always listening. — **David J. Eicher**

The barred spiral galaxy M83 is a Milky Way look-alike.

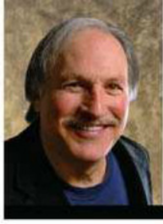
ESO/IDA/DANISH 1.5M/R. GENDLER, S. GUISARD; COMET ISON: V. NEVSKI/A. NOVICHONOK; ROCKS ON MARS: NASA/JPL-CALTECH/MSSS; COMET PANSTARRS: K. ROCHOWICZ/E. GUIDO/N. HOWES/G. SOSTERO

BREAK THROUGH



Sugar in Ophiuchus

The Rho Ophiuchi star-forming region ranks among the sky's most colorful nebulae in visible light. This nearby stellar nursery isn't too shabby at infrared wavelengths, either. In this view from the Wide-field Infrared Survey Explorer (WISE) spacecraft, blue and cyan trace starlight while green and red reveal dust emission. In August, astronomers using the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile's Atacama Desert announced their discovery of sugar molecules — a fundamental building block of life — in the gas surrounding one of the nebula's young Sun-like stars. NASA/JPL-CALTECH/WISE TEAM



STRANGE**UNIVERSE**

BY BOB BERMAN

It's random

Accomplishing a complex task by mere chance creates seemingly endless possibilities.

As observers, we assume random events created most of what we see in the universe. The cratering pattern in the Moon's southern region appears as random as a jackal's markings. And in the quantum world of the tiny, we only understand things probabilistically. This works splendidly. Yet "chance" is a fascinating process that's often misunderstood.

A famous illustration of "probability" is the monkeys-and-typewriters thing. We've all heard it: Let a million monkeys type randomly on a million keyboards for a million years, and you'd get all the great works of literature. Is this true?

About 10 years ago, a couple of wildlife caretakers actually put out a bunch of typewriters in front of a group of macaques to see what would happen. The animals typed virtually nothing. Instead, they threw some of the machines on the ground, used them as toilets, and quickly rendered all of the machines useless. They didn't create any written wisdom whatsoever.

Well, ha ha and LOL, but let's get serious. We'll confine the experiment to our thoughts the way Albert Einstein liked to do. So could a million diligent monkeys typing for a million years truly create *Hamlet*? And if one of them wrote *Moby Dick* word for word on his 97 billionth attempt at pounding random keystrokes but then left out the period at the end, would that count?

Believe it or not, such a problem is entirely solvable. Now, keyboards offer a lot of places to push; there are 58 keys even on old-fashioned typewriters. When talking about random events, consider the difficulty of creating merely the 16 opening characters, including the appropriate spaces, of *Moby Dick*, "Call me Ishmael." How many random tries would be needed?

Given 58 possible keys, it would be 58 × 58 × 58 × 58 ... 16 times over, which is 16.4 trillion quadrillion attempts. But remember that we have a million monkeys working, and let's say they type 45 words a minute, so the 16 keystrokes that make up the three words take just four seconds. And they never rest or sleep. How much time then, according to probability, before *one* of them gets a 50-50 chance at typing that famous opening line?

POSSIBILITIES ARE ALWAYS INSANELY ENORMOUS. THEY SURPRISE US.

Answer: about 2,100 trillion years, or roughly 153,000 times the age of the universe.

So a million monkeys typing furiously would never even reproduce one book's short opening line. Moral: Forget the monkeys-and-typewriters thing. It's bogus.

Worse, it overly credits the power of random events. As a corollary, if you're a longtime reader, you know I share former *Encyclopedia Britannica* Publisher Paul Hoffman's views about consciousness — that it's the greatest mystery in all of science. How could random atom collisions ever give creatures a sense of *perception*?

Astronomers hope to find life elsewhere, and many assume that an alien's self-awareness would have arisen through random physical or chemical processes. I'm not advocating any philosophical viewpoint here; I'm merely saying that the random supposition is simply not any kind of useful hypothesis. The "random" business is given far more potency in the popular imagination than it deserves. We'd do better to candidly say, "This is a mystery." Then maybe some researchers could begin to tackle it from scratch.

Accomplishing a particular complex task by mere chance is what we're examining. Its limitations may seem puzzling because random events do indeed create dizzying possibilities.

Consider all of the ways you can arrange four books on a shelf. You find the possibilities by multiplying 4 × 3 × 2 — pronounced "4 factorial" and written 4! — which is 24. But what if you have 10 books? Easy again: it's 10! or 10 × 9 × 8 × 7 × 6 × 5 × 4 × 3 × 2, which is — ready? — 3,628,800 different ways. Going from four items to 10 increases the possible arrangements from 24 to 3.6 million. So if you haphazardly put 10 books on a shelf, the chances are 3.6 million to one against them appearing alphabetically. Few of us would expect such long odds — 100 to one sounds more plausible, doesn't it?

Possibilities are always insanely enormous. They surprise us. The number of atoms in the entire visible universe can be written right here: 100,000, 000,000,000,000,000,000,000, 000,000,000,000,000,000,000, 000,000,000,000,000,000,000, 000,000,000,000 — that's 80 zeros. Add just six more zeros (you'd hardly notice them), and you've represented all the atoms in a million universes.

But you'd have to type zeros for the rest of your life to express the ways — just the written representation and not the actual count — that stars can be arranged in our galaxy. Or neurons can connect in a human brain. The mind's potential lies beyond its own comprehension.

We can always count *things*. No problem there. But when it comes to assessing *possibilities* — on Earth or off it — we monkeys haven't got a chance.

Contact me about my strange universe by visiting **http://skymanbob.com.**

FROM OUR INBOX

Kudos for an excellent historical guide

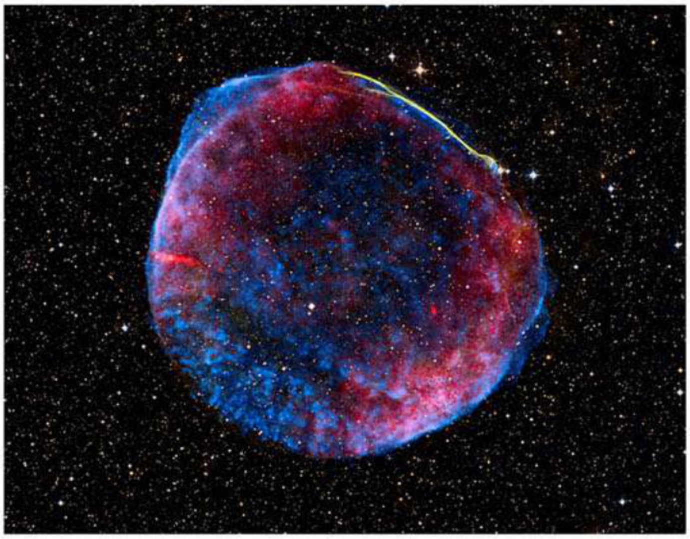
Thanks to Karri Ferron and *Astronomy* for "The Red Planet's colorful past" (August 2012). As an instructor who teaches adult education classes about the Mars canal controversy and the extraterrestrial life debate, I thoroughly enjoyed Ferron's informative and richly illustrated treatment of a fascinating subject.

It may be of additional interest that Camille Flammarion (1842–1925), mentioned on page 47, was much more than a writer of science fiction; he was, above all, a highly effective and ubiquitous popularizer of astronomy in his native France and beyond. *Astronomie populaire* (1880), Flammarion's most successful work, went through more than 50 editions and was translated into at least 11 languages, including English. A well-documented account of Flammarion's career and his major writings in strong support of multiple inhabited worlds, including *La planète Mars* (1892), appears in Michael J. Crowe's *The Extraterrestrial Life Debate, 1750–1900* (Dover, 1999). — **Lee Minnerly,** Chicago

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman.**

ASTRONEWS

KEPLER'S REVENGE Kepler's supernova remnant, the debris of a 1604 stellar explosion, was likely more powerful and distant than previously thought, according to research in the September 1 issue of *The Astrophysical Journal.*



DOUBLE DEATH? Astronomers searched the site of SN 1006, a historic type Ia supernova, looking for a leftover companion, but found none. The explosion therefore resulted from the collision of two white dwarfs or a white dwarf stealing material from a star less massive than the Sun, say scientists. X-RAY: NASA/CXC/RUTGERS/G. CASSAM-CHENAÏ, J. HUGHES, ET AL.; RADIO: NRAO/AUI/NSF/GBT/VLA/DYER, MADDALENA & CORNWELL; OPTICAL: MIDDLEBURY COLLEGE/F. WINKLER, NOAO/AURA/NSF/CTIO SCHMIDT & DSS

WHAT CAUSED SUPERNOVA 1006?

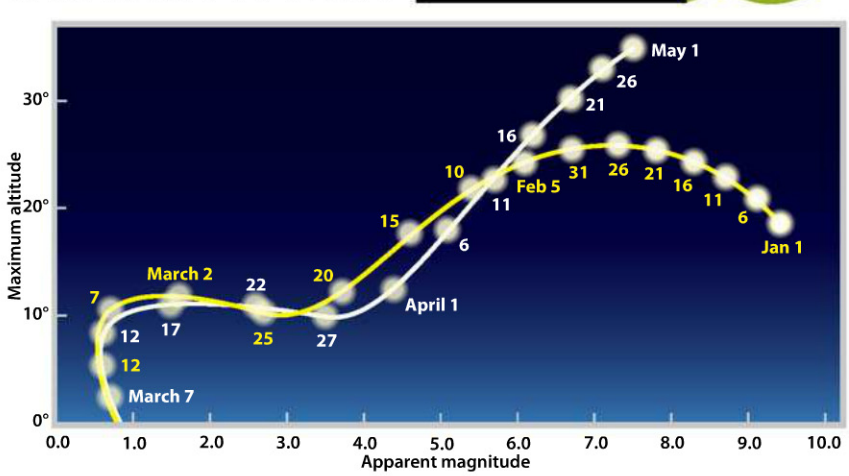
An international team of astronomers has searched the region around the historical stellar blast SN 1006 looking for a survivor. The explosion was a type Ia supernova, which results when a white dwarf (the remnant of a once Sun-like star) collects enough mass to explode and destroy itself. Astronomers continue to question how a white dwarf gets that extra material — from merging with another white dwarf or by siphoning gas off a larger companion star — and have found evidence of both methods.

In a new study, which appeared in the September 27 issue of *Nature*, scientists did not find a leftover companion star within 4 arcminutes of the explosion site of SN 1006, nor did they find any with telltale iron components in their characteristic light spectra. Thus, the team says, the historical supernova resulted either from two white dwarfs colliding or, less likely, from a white dwarf stealing material from a star that has less mass than the Sun and thus is not bright enough to be visible in any images taken of the site. — **Liz Kruesi**

A BRIGHT COMET GETS READY TO SHINE

C/2011 L4 should peak near magnitude 0.5 during the second week of March.

FAST FACT



COMET TRACKS. Comet C/2011 L4 (PANSTARRS) promises to be one of the brightest comets of the past decade. This illustration plots the comet's peak altitude against its predicted magnitude during the first four months of 2013 from a latitude of 30° north (white) and 30° south (yellow). Altitudes represent the comet's position at either the beginning or end of civil twilight, when the Sun lies 6° below the horizon. *ASTRONOMY*: RICHARD TALCOTT AND ROEN KELLY

BRIEFCASE

TITAN'S SEASONS

Incorporating 30 years of data from space missions and ground-based observatories, scientists have observed how the atmosphere of Saturn's moon Titan changes over a complete solar orbit. The deeper layers of the moon's atmosphere show more rapid changes than expected. Athena Coustenis of Paris-Meudon Observatory in France presented her team's results September 28 at the European Planetary Science Congress in Madrid. — **L. K.**

SEEING POWER

The 570-megapixel Dark Energy Survey camera took its first image September 12. Attached to the 4-meter Blanco Telescope at Cerro Tololo Inter-American Observatory in Chile, the camera will survey 5,000 square degrees of sky over the next five years to measure 300 million galaxies and learn about dark energy, the mysterious force that seems to be speeding up cosmic expansion. — **L. K.**

STELLAR MAGNETISM

The massive O-type star NGC 1624–2 has a magnetic field about 20,000 times stronger than the Sun's and nearly 10 times stronger than any other massive star, according to a September 11 paper in the *Monthly Notices of the Royal Astronomical Society.* The heavy star, about 35 times the Sun's mass, lies about 20,000 light-years away in the open star cluster NGC 1624. — **Bill Andrews**

25 years ago in *Astronomy*

The January 1988 issue featured a version of former astronaut Sally K. Ride's NASA report "Leadership and America's Future in Space." She wrote, "In the aftermath of the *Challenger* accident, reviews of our space program made its shortcomings starkly apparent."

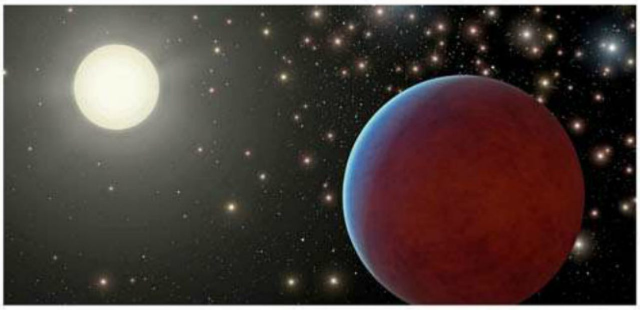
As *Astronomy*'s editors summarized, Ride proposed four long-range programs for NASA: "a global study of Earth, an advanced program of solar system exploration, a permanent return to the Moon, and a pioneering manned journey to Mars." The latter two remain goals even now.

10 years ago in *Astronomy*

In the January 2003 issue, Phil Plait and Lynette Cook took readers "Under Alien Skies." Plait, now best known as the "Bad Astronomer," described how the cosmos would look from an extrasolar planet, and Cook illustrated the possibilities. "The sky we see is the product of a very specific set of circumstances," Plait wrote. "If we were to drastically change the factors … how would this affect what we see?"

From a planet within the Orion Nebula to one orbiting a red dwarf, each of the alien scenes proved exotic, fascinating, and eerily beautiful. — **B. A.**

ASTRO**NEWS**



PRAESEPE'S PLANETS. For the first time, astronomers have found planets orbiting stars in an open cluster: the Beehive Cluster (M44), also known as the Praesepe. While uninhabitable, these worlds would have skies full of stars, as shown in this illustration. NASA/JPL-CALTECH

First planets found around Sun-like stars in cluster

Exoplanets, worlds that orbit stars other than the Sun, have turned up in unexpected places ever since their discovery nearly 20 years ago. Now, astronomers have found for the first time two gas giants orbiting Sun-like stars in a star cluster, according to a paper in the September 10 issue of *The Astrophysical Journal Letters*.

The planets orbit stars within the Beehive Cluster (M44), also known as the Praesepe, a loose collection of suns that formed at about the same time, some 600 million years ago. The worlds follow the typical naming convention for exoplanets — adding a "b" to the star's designation — and are therefore known as Pr0201b and Pr0211b.

"These are the first 'b's' in the Beehive," says lead author Sam Quinn of Georgia State University in Atlanta. He added that the findings confirmed long-held suspicions about planet formation. "We know that most stars form in clustered environments like the Orion Nebula, so unless this dense environment inhibits planet formation, at least some Sun-like stars in open clusters should have planets. Now, we finally know they are indeed there."

The exoplanets are massive gas giants that orbit their stars extremely closely, making them model members of the "hot Jupiter" class. Astronomers theorize that such worlds must form farther away from their suns and slowly migrate closer, a process these findings could shed light on.

"The relatively young age of the Beehive Cluster makes these planets among the youngest known," says co-author Russel White, also of Georgia State University. "And that's important because it sets a constraint on how quickly giant planets migrate inward — and knowing how quickly they migrate is the first step to figuring out how they migrate." — **B. A.**

QUICK TAKES

COOL CHEMISTRY
A September 1 study in *The Astrophysical Journal Letters* shows how natural solar system processes can turn frozen organic materials into the forerunners of life's building blocks.

●

DETERMINING DEIMOS
A technique to calculate the most precise orbit of the martian moon Deimos appeared in the September issue of *Astronomy & Astrophysics.*

●

PLANETARY PURSUIT
A September 11 paper in *Nature Communications* argues that the chaotic conditions in the center of the Milky Way are capable of producing planets.

●

UWINNING!
Uwingu, a commercial astronomy-related startup, announced September 26 that it had successfully raised more than $75,000, which it plans to use to further space research.

●

ECCENTRIC STUDIES
A paper in the October *Astrobiology* describes a way to extend a star's habitable zone to include worlds with eccentric (highly elliptical) orbits.

●

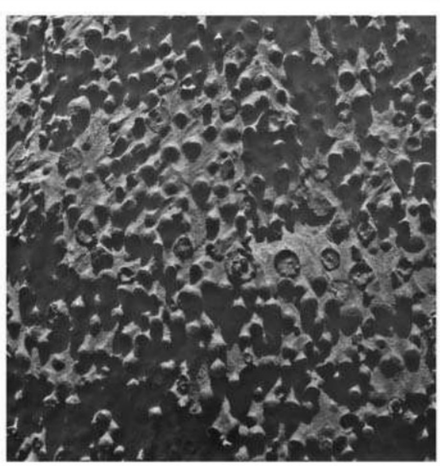
WEBB WORK
The first two primary mirrors (out of 18 total) for NASA's James Webb Space Telescope arrived for testing, the agency announced September 24.

●

HALEY'S COME
The team behind NASA's long-lived Mars Exploration Rovers, Spirit and Opportunity, received the Haley Space Flight award September 12. — **B. A.**

Rover finds odd spherules on Mars

SPHERULE SIGHTING. More than 8.5 years after discovering an odd outcrop of spherical objects near its landing site, the Mars rover Opportunity has found a set of reminiscent spherules 22 miles (35 kilometers) away, as shown in this image released September 14. But these small, round particles are not the iron-rich "blueberries" Mars scientists have become familiar with. Instead, the new ones found at the Endeavour Crater outcrop "Kirkwood" differ in concentration, internal structure, composition, and distribution. The image Opportunity returned of the new spherules shows that they span up to about ⅛ inch (3 millimeters) each. Currently, their origin remains a mystery, but the rover continues to sample these round particles to test various hypotheses. — **Karri Ferron**



NASA/JPL-CALTECH/CORNELL UNIV/USGS/MODESTO JUNIOR COLLEGE

ASTRO**CONFIDENTIAL** BY KARRI FERRON

FAST FACT The Dawn spacecraft studied Vesta using three instruments: a camera, a visible- and infrared-mapping spectrometer, and a gamma-ray and neutron spectrometer.

WHAT FASCINATED YOU MOST ABOUT DAWN'S EXPLORATION OF VESTA?

Vishnu **Reddy** Research assistant professor at the University of North Dakota and part of the Dawn science team

Vesta is unlike any other object in the asteroid belt as it is the only surviving member of a class of protoplanets that coalesced to form the terrestrial worlds. So Vesta is like a time capsule that allows us to explore the conditions in the early solar system.

The Dawn mission's exploration of Vesta revealed a surface that shows great brightness, color, and compositional variations. Most asteroids that spacecraft have visited so far have "painted themselves gray." But on Vesta, we see bright material that is as white as snow and dark material as black as coal.

We discovered that this dark material is remnant carbonaceous chondrite asteroid(s) that impacted Vesta in the past. We know this because such matter also exists in inclusions in Howardite-Eucrite-Diogenite meteorites from Vesta. But what surprised the Dawn team is the abundance of this dark material and the fact that it contains about 6 percent water by weight. This suggests that primitive asteroids were responsible for the transportation of carbon and volatiles in the inner solar system and could have helped life evolve on Earth.

Studying Vesta's mineralogy is important because, like the terrestrial planets, it is a differentiated object. At one point, Vesta's interior was molten, which led to the formation of a core, mantle, and crust. This crust is primarily made of lava flows similar to what we see on Earth. But Vesta's lavas are different from those we see in Hawaii because of the conditions under which they formed. We were expecting to find these volcanic features on Vesta's surface, but eons of impacts have erased any trace of its basaltic past. For me, this was the most surprising result from Dawn's mission to Vesta.

LUCILLE LE CORRE

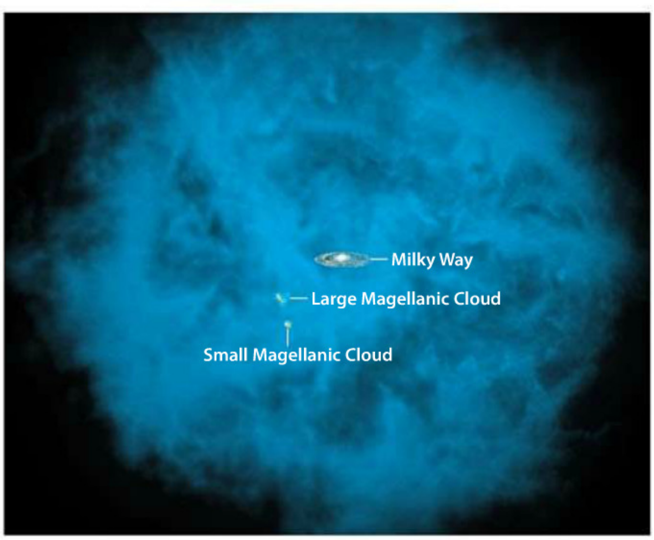
ASTRO**NEWS**

MAGNETIC MONSTER Scientists report in a September 11 *Monthly Notices of the Royal Astronomical Society* paper that they found the most magnetic star yet, with a magnetic field about 20,000 greater than the Sun's.

Huge gas cloud surrounds Milky Way

An enormous cloud of hot gas likely extends hundreds of thousands of light-years around the Milky Way Galaxy, scientists announced in a September 1 paper in *The Astrophysical Journal Letters*.

The huge halo of material (unrelated to the dark matter that also surrounds our galaxy) is comparable in mass to the sum of the Milky Way's stars and could solve a longstanding astronomical mystery.

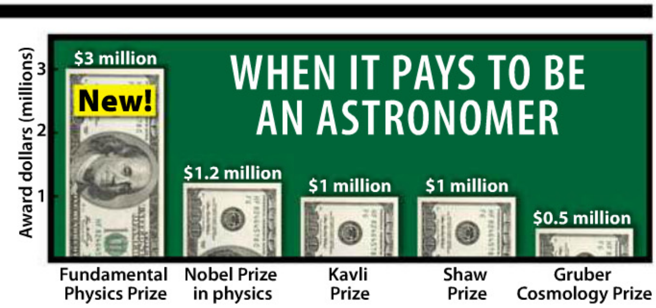


IT'S A GAS! Recent observations suggest that the Milky Way lies amid a halo of hot gas, potentially solving a mystery involving missing matter. In this visualization, the gas (blue) has a radius of 300,000 light-years around our galaxy, but it could actually reach much farther. NASA/CXC/M. WEISS /OHIO STATE/A. GUPTA, ET AL.

Studies of various galaxies, including the Milky Way, have shown them to lie in the midst of hot gas, with temperatures up to millions of kelvins (hundreds of times hotter than the surface of the Sun). "We know the gas is around the galaxy, and we know how hot it is," says lead author Anjali Gupta of Ohio State University in Columbus. "The big question is: How large is the halo, and how massive is it?"

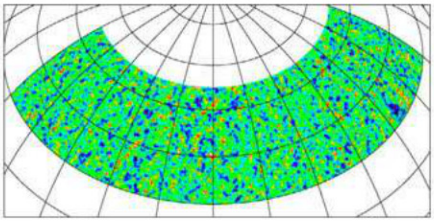
The answer in both cases turns out to be: very. The authors estimate the mass to be at least as much as 10 billion solar masses, and perhaps as much as 60 billion. Its size is less easy to pin down, but co-author Smita Mathur, also of Ohio State University, says, "It may extend for a few hundred thousand light-years around the Milky Way, or it may extend farther into the surrounding Local Group of galaxies. Either way, its mass appears to be very large."

The cloud's existence provides a potential solution to the "missing baryon" problem — the fact that astronomers couldn't find about half of the basic particles of matter they expected to find in our galaxy. The gas' density is so slight that it had simply gone unnoticed until now. — **B. A.**



TRIPLE PAYOUT. In 2012, billionaire Internet mogul Yuri Milner awarded nine scientists his new Fundamental Physics Prize with a reward that dwarfs all others in astronomy. Unlike those other recognition programs, though, this prize can be awarded to theorists whose ideas haven't yet been proven. *ASTRONOMY*: KARRI FERRON AND ROEN KELLY

ASTRONEWS



TELLTALE RADIATION. Scientists analyze the Big Bang's leftover radiation, called the cosmic microwave background, to learn about the universe's properties. In a recent study, astronomers used the data to determine when the first stars and galaxies formed, and their effect on their environments. SOUTH POLE TELESCOPE COLLABORATION

When the first stars and galaxies lit up the cosmos

Astronomers with the South Pole Telescope (SPT) say the first stars and galaxies began forming when the universe was only about 250 million years old. The team published its findings in the September 1 issue of *The Astrophysical Journal*.

The SPT is a 10-meter instrument in Antarctica that observes millimeter wavelengths, which lie in the microwave portion of the electromagnetic spectrum. Astronomers use this telescope to study the leftover radiation from the Big Bang, called the cosmic microwave background (CMB). This radiation shows what the universe's structure looked like at just 380,000 years after the Big Bang.

The SPT observes about 2 percent of the sky in high resolution to document extremely small details within the CMB. Intervening matter between this background radiation and today can create distortions in the CMB. (This process is similar to how an imperfect glass window can warp a background object. If you map those distortions, you learn about the foreground window's properties.)

SPT scientists looked for the interaction between the CMB and electrons associated with high-energy radiation emitted by the first stars and galaxies. This emission ionized the hydrogen gas near those structures; astronomers can then tease the signature of this effect out of the CMB. From that information, they determined when these objects began forming and also that this era of the first structures lasted less than 500 million years. Thus, about 750 million years post-Big Bang, these stars and galaxies had emitted enough light to ionize the universe's hydrogen. — **L. K.**

45° FAHRENHEIT (7° Celsius)

The high temperature on Mars, according to Curiosity. The rover took this measurement September 28, during martian winter.

SECRET SKY

BY STEPHEN JAMES O'MEARA

The phantom bridges of Sinus magnus

What will you see in this oft-debated region of the Orion Nebula?

When Dutch astronomer Christiaan Huygens published his detailed sketches and drawings of the Orion Nebula's (M42) central parts (now known as Huygens' Region) in 1659, other observers began to follow suit.

Over the next two centuries, astronomers compared the published results and pondered whether the nebula underwent periodic changes. Alternatively, they wondered: Did the differences between the drawings actually reflect more mundane issues, such as the vagaries of Earth's atmosphere, differing telescope sizes, magnifications used, and the artist's impression?

While we now know the latter is true, you might find it fun and enlightening to make your own visual study of the region over time, using the same aperture and magnification. The differences, no matter how subtle, might surprise you.

The Fish's Mouth

I suggest you start your journey by examining one of the more dramatic features of the nebula — a region popularly known as the Fish's Mouth. Easily distinguishable as a dark bay east of the famous Trapezium of stars, it received the label Sinus magnus (Great gulf) from British astronomer William Herschel.

One fascinating contrast effect occurs if you concentrate your gaze directly on Sinus magnus. With time, a powerfully dark image appears. It is a mighty silhouette that flows away from an hourglass-shaped light just northeast of the Trapezium (the Fish's Eye) and runs between the Fish's bright jaws. When Herschel observed this gulf with a 10-foot reflector November 11, 1776, he saw it as "a total darkness."

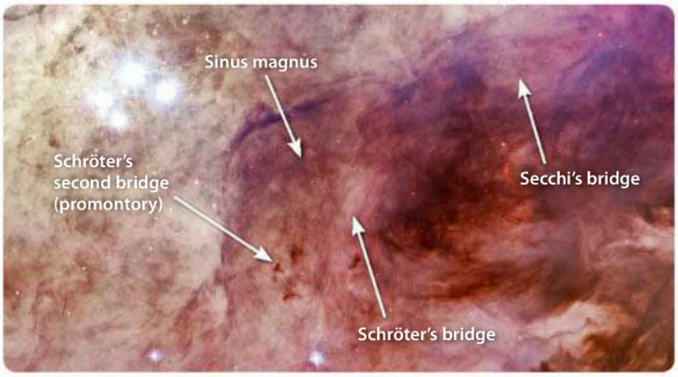
Sinus magnus remained a featureless cavity until January 25, 1797, when German astronomer Johann Schröter observed, and subsequently drew, two streaks of light crossing the bay. About three weeks later, however, he could make out only the brighter northern point of the easternmost streak. By December 10, 1797, the eastern streak returned as a "faint trace" while the other feature never came back.

Curiously, no other observers are known to have spotted these streaks again until 1857, when Italian astronomer Angelo Secchi noted, "The bottom of the gulf is separated from the rest by the *bridge of Schroeter*, the variability of which is, it seems to me, indubitable." Secchi saw the streak as "a true bridge formed by light veils of mist that traverse the gulf. … I find but a very faint trace of the other branches that may be seen as promontories in the gulf following the principal *bridge*, and that now have become brighter. But a little mist in the atmosphere causes all these minute details to disappear."

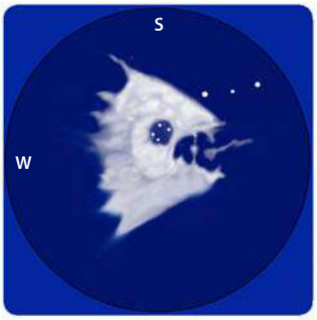
On January 15, 1858, Secchi observed Sinus magnus and was surprised to discover nebulosity within it in the shape of the "figure 8" on its side (with south up), with Schröter's bridge separating the figure's hollows.

The next decade, he saw this aspect again. A new bridge formed its eastern edge; Secchi made no mention of Schröter's other bridge. In Secchi's 1868 drawing, the two bridges stretch across the southern half of the bay and connect to a fainter spit of mist jutting from the northern part of the Fish's mouth.

All these sightings continued to mystify observers until the advent of photography, which resolved the age-old visual dilemma. Now it's your turn to test your vision and see how Earth's atmosphere plays tricks on the eye. Remember to keep good records, and send results to someara@interpac.net.



The phantom bridges of Sinus magnus within the Orion Nebula (M42) kept observers guessing for centuries as to the area's true appearance. In this Hubble photo, south is up and west is to the left. NASA/ESA/M. ROBBERTO (STScI/ESA)/HUBBLE SPACE TELESCOPE ORION TREASURY PROJECT TEAM



STEPHEN JAMES O'MEARA

The Fish's Mouth comes alive in this rendering from the author, which he based on views through Tippy D'Auria's 18-inch Dobsonian at the 1990 Winter Star Party.

COSMIC WORLD

A look at the best and the worst that astronomy and space science have to offer. **by Bill Andrews**

Cold as space ← → Supernova hot

Wrong Neil

NBC News announces, "Astronaut Neil Young, first man to walk on moon, dies at age 82." That's one small slip for a writer, one giant blunder for NBC.

Plague party

Squirrels near Palomar Mountain Observatory test positive for the bubonic plague, giving local astronomers one more excuse to act weird.

Tatooine scene

The Kepler mission discovers the first circumbinary multiple-planet system — where the worlds orbit two stars. Whose *Star Wars* fanfic is too unrealistic now, critics?

Martian music

NASA's Curiosity rover broadcasts the first song from the surface of Mars, will.i.am's "Reach for the Stars." The Black Eyed Peas' galactic domination continues!

NASA (WRONG NEIL); DAVEFOC (PLAGUE PARTY); NASA/JPL-CALTECH/T. PYLE (TATOOINE SCENE); NASA (MARTIAN MUSIC)

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/O'Meara.**

 GROWING PAINS The young Sun produced numerous shock waves that affected the order in which the planets formed, according to a presentation September 27 at the European Planetary Science Congress in Madrid.

ROVER'S RIVER ROCKS. NASA's Curiosity rover has found rocks on Mars, such as the outcrop named Link (left), strikingly similar to ones on Earth (right) formed by flowing water. NASA/JPL-CALTECH/MSSS AND PSI

Mars rover finds proof of ancient stream

NASA's Mars Science Laboratory sure didn't waste any time. Within two months of landing on the Red Planet on August 6, the Curiosity rover found evidence that it's treading upon an ancient streambed that once flowed within the martian crater Gale. NASA announced the discovery September 27.

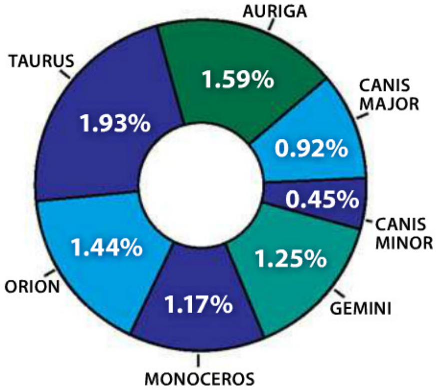
The rover, which is searching for signs of past habitability on Mars, discovered familiar types of gravels within rocks typically shaped by rushing liquid. "From the size of gravels it carried, we can interpret the water was moving about 3 feet [1 meter] per second, with a depth somewhere between ankle and hip deep," says Curiosity science co-investigator William Dietrich of the University of California, Berkeley.

Scientists already knew Mars was no stranger to liquid water, but this is the first time they've spotted direct evidence of a flowing stream. — **B. A.**

FAST FACT

88 constellations cover the sky; there are no gaps or overlaps.

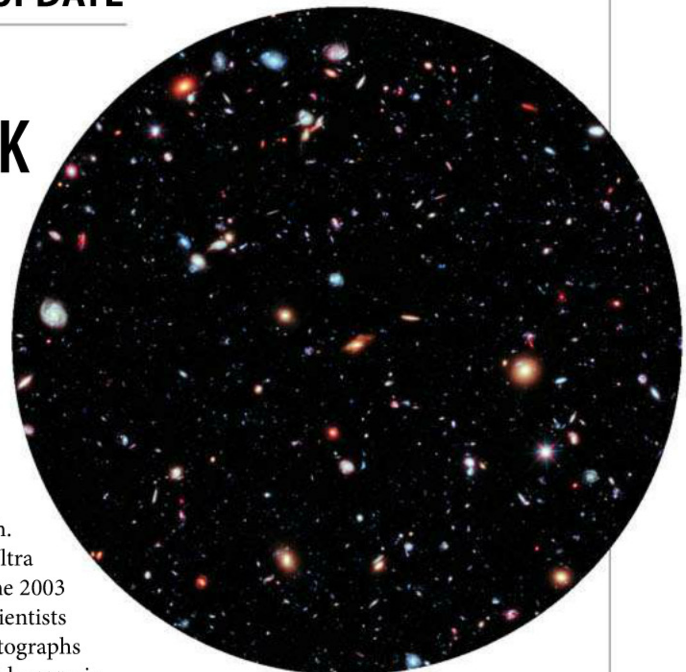
HOW BIG IS THAT CONSTELLATION?



CONSTELLATIONS COMPARED. This chart shows the relative sizes of January's nighttime star patterns. Percentages give total sky coverage. *ASTRONOMY*: ROEN KELLY

SPACE SCIENCE UPDATE

HUBBLE LOOKS BACK — AGAIN



COSMIC HISTORY. Combining more than 2,000 Hubble Space Telescope images to create this eXtreme Deep Field photograph, scientists spied a galaxy from just 450 million years after the Big Bang. NASA/ESA/G. ILLINGWORTH, D. MAGEE, AND P. OESCH (UNIVERSITY OF CALIFORNIA, SANTA CRUZ)/R. BOUWENS (LEIDEN UNIVERSITY)/THE HUDF09 TEAM

Astronomers released the deepest image of the cosmos yet — the eXtreme Deep Field (XDF) — September 25. In this composite, they found the youngest galaxy yet discovered, which dates from just 450 million years after the universe's birth.

Building on the Hubble Ultra Deep Field program (both the 2003 and the 2009/10 releases), scientists incorporated additional photographs taken by the Hubble Space Telescope in near-infrared radiation to look even further back in time. The XDF combines more than 2,000 images spanning 2 million seconds (23 days) of Hubble observations from the Advanced Camera for Surveys and the Wide Field Camera 3 (WFC3) instruments.

Cosmic expansion has stretched the light that left stars and galaxies billions of years ago, so these objects are now visible in longer-wavelength radiation such as infrared. The WFC3 (installed during a 2009 servicing mission) extends the telescope's vision into near-infrared and thus allows scientists to investigate these longer wavelengths. In fact, galaxies that existed less than about 800 million years after the Big Bang appear too red for optical detectors and so require infrared detection, according to Pascal Oesch, a member of the XDF team from the University of California, Santa Cruz. Using the XDF, astronomers can see 96 percent of the way back to the Big Bang — to a time when stars and galaxies were beginning to form.

The deep field image spans 2.3 by 2 arcminutes of sky toward the constellation Fornax; in comparison, the Moon's diameter is about 30 arcminutes. The XDF combines about 250 gigabytes of data.

The XDF team says that to observe the first galaxies that formed — those earlier than 400 million years after the Big Bang — scientists will need the infrared detectors of the future James Webb Space Telescope, scheduled to launch in 2018. — **L. K.**

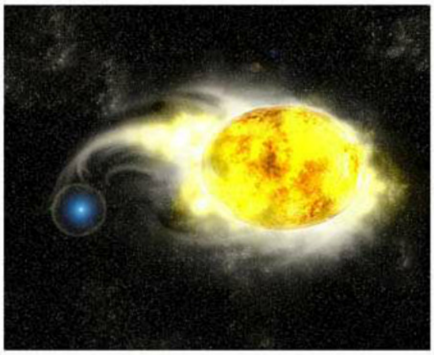
A galactic odd couple

NASA/ESA/THE HUBBLE HERITAGE (STScI/AURA)-ESA/HUBBLE COLLABORATION

OPPOSITES ATTRACT. A pair of star cities clearly displays the dramatic differences between elliptical and spiral galaxies in this Hubble Space Telescope image released September 6. Collectively known as Arp 116, the duo lies roughly 9 million light-years apart, quite close by cosmic scales. The elliptical in the center, M60, is roughly 50 percent larger than the spiral NGC 4647 and much more massive. Although studies don't conclusively indicate that the two are interacting, they are visible from Earth at the same scale and therefore exemplify how the two types of galaxies differ in size, structure, and color. — **K. F.**

FAST FACT

The earliest known supernova is SN 185, spotted within Circinus the Compasses in A.D. 185 by Chinese astronomers.



EXPLOSIVE COMBINATION. Scientists suspect that Supernova 2011dh erupted from a yellow supergiant star that was losing material to a massive blue companion star, as shown in this illustration. KAVLI IPMU/AYA TSUBOI

Yellow supergiant likely caused 2011 supernova

Astronomers have found evidence suggesting that the progenitor star that erupted into a 2011 supernova was a yellow supergiant that few had suspected. That's because they thought that kind of stellar explosion — known as a type IIb — was strictly the work of a red supergiant or a compact blue star. A paper in the September 20 issue of *The Astrophysical Journal* presents the data, as well as a potential test of the hypothesis.

When SN 2011dh first appeared in May 2011 within the Whirlpool Galaxy (M51), astronomers immediately began studying the bright supernova, including a search in archival images for the star that it had been. They soon found, and discounted, a yellow supergiant in the local vicinity, but the new work shows that only such a star could produce the explosion's particular emissions. Specifically, the paper suggests that the supergiant was part of a binary system, along with a massive blue star that was leeching material off the yellow supergiant.

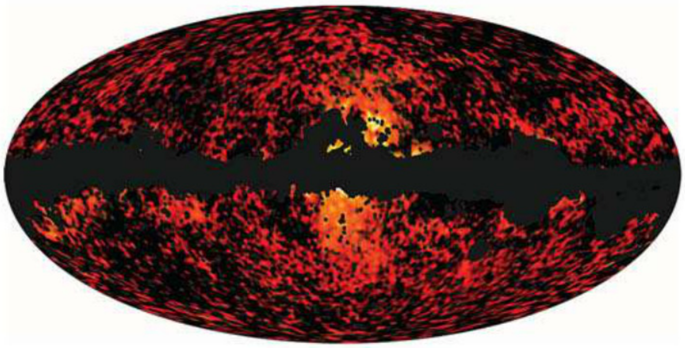
If future observations detect this blue star, which is currently too faint to see so near the still-bright supernova, it will provide definitive proof that the yellow supergiant was the cause of SN 2011dh. — **B. A.**

250,000+

The number of people who have participated in the Galaxy Zoo project since it launched in 2007, according to a September 10 announcement from the University of Oxford.

DISTANT DISCOVERY NASA announced September 19 that it had found a new candidate for the farthest galaxy known, one whose light first shone 13.2 billion years ago.

Milky Way's haze not from supernovae?



DARK MATTER? Scientists with the Planck microwave mission say the Milky Way's central haze results not from supernovae explosions but perhaps from interactions between dark matter particles. ESA/PLANCK COLLABORATION

The European Space Agency's Planck microwave spacecraft has been observing the entire sky for more than three years. While its main scientific goal is to further study the Big Bang's residual radiation — the cosmic microwave background — astronomers also have used its data to learn about our galaxy. Years of observations show a haze around the galactic center stretching to tens of thousands of light-years; this structure matches the shape of that discovered by astronomers in 2009 processing data from the Fermi Gamma-ray Space Telescope.

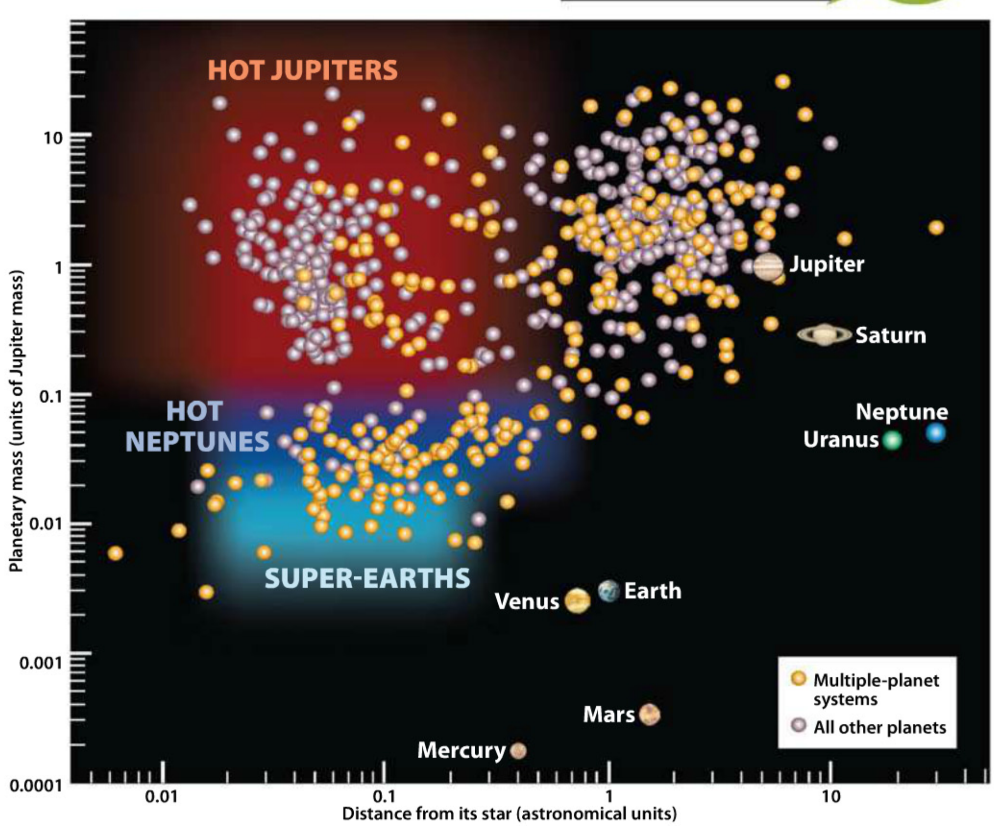
With Planck, however, researchers pieced together the intensity of radiation across a broader range. Scientists use this information along with microwave data from the Wilkinson Microwave Anisotropy Probe to learn about the physical processes that would emit the observed radiation. After analyzing the microwave data of the Milky Way's central haze, Planck team members say supernovae could not be responsible for this radiation, according to a study submitted to *Astronomy & Astrophysics* August 29.

Some team members think interactions between particles of dark matter — the mysterious invisible material that makes up about 85 percent of the Milky Way's mass — could create the haze. — **L. K.**

HOW EXOPLANETS COMPARE TO THE SOLAR SYSTEM

NASA's Kepler spacecraft has found more than 2,000 planet candidates.

FAST FACT



UNIQUE WORLDS. Scientists have discovered nearly 800 extrasolar planets by the transit method or the movement of their stars (radial velocity method). These techniques allow the researchers to calculate the exoplanets' masses, and thus compare them to the worlds in our solar system. They're finding that these exoplanets don't look much like our home planetary system — they tend to be more massive and orbit closer to their stars. *ASTRONOMY:* LIZ KRUESI AND ROEN KELLY, BASED OFF DATA FROM THE EXTRASOLAR PLANETS ENCYCLOPEDIA

IT'S ELEMENTAL. Minerals high in magnesium and sulfur cover Mercury's surface, according to recent X-ray observations of the planet. NASA/JHUAPL/CARNEGIE INSTITUTION OF WASHINGTON

Mercury's surface surprises

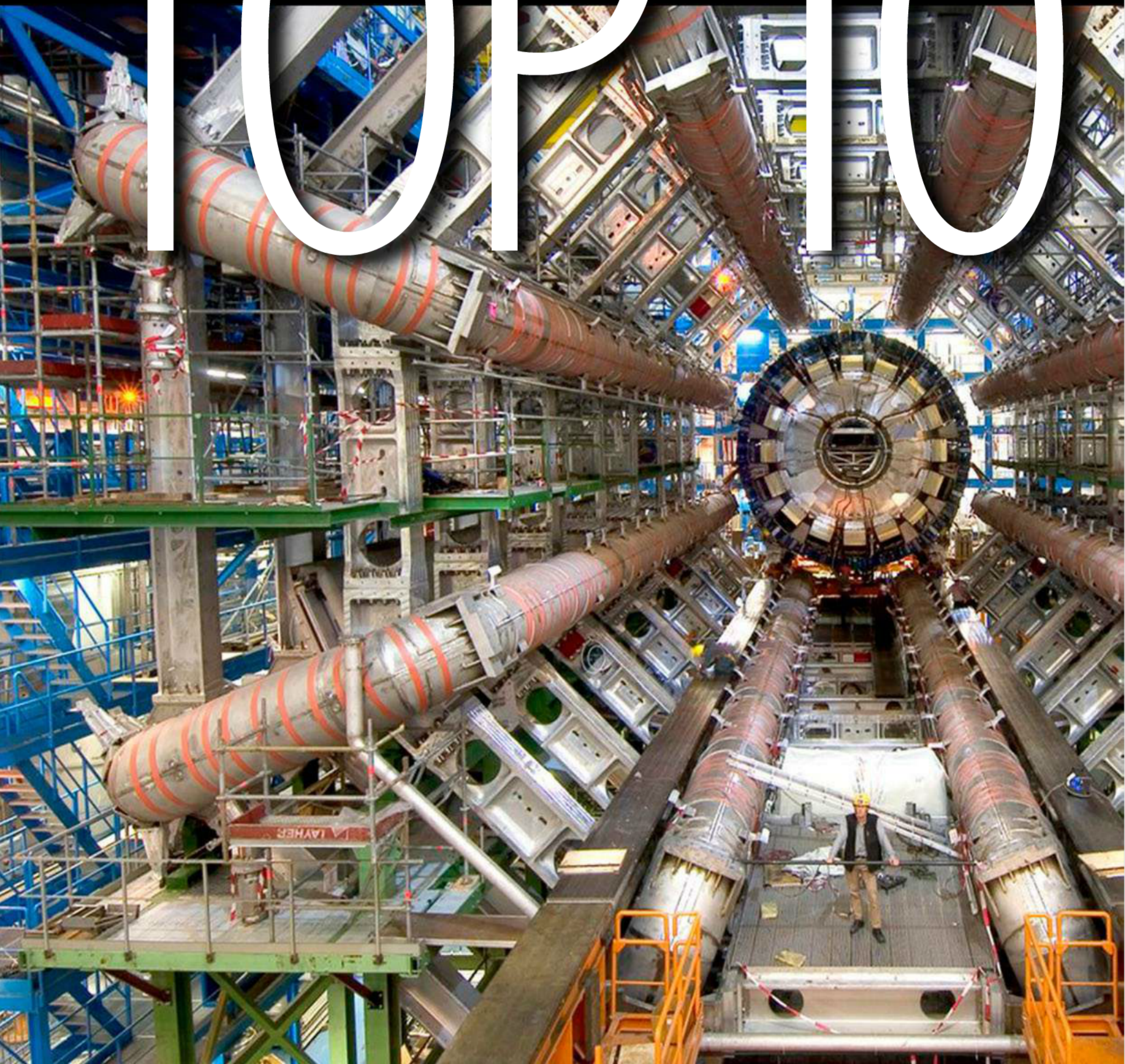
The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft has helped scientists understand the innermost planet, and a paper published October 3 in the *Journal of Geophysical Research* describes additional discoveries. Using MESSENGER's X-ray Spectrometer — which records the high-energy X-ray emissions from the planet's surface after solar X-rays impact it — scientists determined that Mercury's surface composition is unlike that of the solar system's other terrestrial planets.

Shoshana Weider of the Carnegie Institution of Washington and colleagues analyzed 205 measurements of magnesium, sulfur, calcium, silicon, and aluminum and found that minerals high in magnesium and enriched in sulfur dominate the surface of the innermost world. Their observations also suggest that the smooth volcanic plains in Mercury's northern latitudes resulted from a magma source chemically different from the material in surrounding areas that are heavily cratered. — **L. K.**

99.996%

The likelihood that dark energy really is the reason behind the accelerating expansion of the universe, according to an upcoming paper in the *Monthly Notices of the Royal Astronomical Society*.

TOP 10



One of this past year's biggest news stories was the discovery of a new particle, seen in data from A Toroidal LHC Apparatus at the Large Hadron Collider in Europe.

SPACE STORIES OF 2012

CERN/MAXIMILIEN BRICE

Astronomers found tiny galaxies ferociously forming stars, the most advanced planetary rover safely touched down on Mars, and physicists discovered a particle they've been seeking for 40 years.

by Liz Kruesi

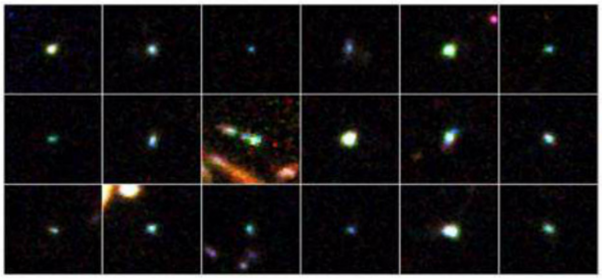
Each year seems to bring greater discoveries and bigger news in the world of astronomy — and 2012 was no exception.

A thrilling landing on the Red Planet excited scientists and the public scattered across the globe. The Hubble Space Telescope continued to find surprising objects in the distant universe. The current financial climate required researchers to prioritize not only what projects received funding, but also how they garnered that funding. And, of course, the scientific community expected big things of the most powerful accelerator, located at CERN, the European high-energy physics laboratory, and in 2012 it certainly delivered.

As the editors of *Astronomy* magazine looked back at the past year, we were excited to rank these and other important space stories.

Liz Kruesi *is an* Astronomy *associate editor.*

10 Dwarf galaxies and stellar formation



Dwarf galaxies that lived about 9 to 10 billion years ago had bursts of star formation, say astronomers. This image shows 18 of the 69 studied. NASA/ESA/A. VAN DER WEL (MAX PLANCK INSTITUTE FOR ASTRONOMY)/H. FERGUSON AND A. KOEKEMOER (SPACE TELESCOPE SCIENCE INSTITUTE)/THE CANDELS TEAM

Dwarf galaxies are the most numerous type of star city in the cosmos. These objects contain about 1 billion times the Sun's mass, which is roughly a hundredth the size of the Milky Way. To learn how these dwarf galaxies formed, astronomers try to observe ever further into the past.

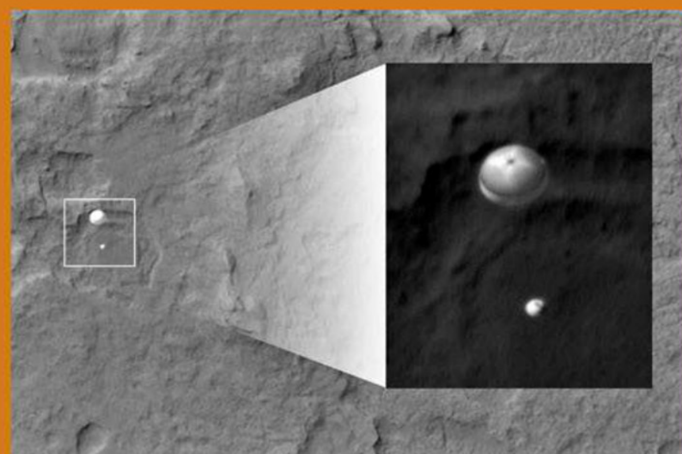
One project aiming to do just that is the Cosmic Assembly Near-IR Deep Extragalactic Legacy Survey (CANDELS). In late 2011, astronomers with CANDELS uncovered 69 dwarf galaxies in a region covering 279 square arcminutes (about one-third the size of the Full Moon). These galaxies all lie about 9 to 10 billion years into the past — around 4 billion years after the Big Bang — and show a bright signature at a wavelength of light that corresponds to intense star formation.

Young stars emit a lot of ultraviolet radiation, which "ionizes" nearby oxygen atoms by kicking off two electrons from each to create Oxygen-III (OIII) ions. This ion emits a line in the electromagnetic spectrum that typically shows up with a green color. However, because of cosmic expansion, this OIII line has shifted into the infrared regime. CANDELS uses the Hubble Space Telescope's instruments to detect such objects, and thus effectively see into the past.

These 69 dwarf galaxies, which range from roughly 5 million to 40 million years old (at the time their light left them), each convert 1 to 10 solar masses of gas into stars per year. But because of their size, they'll double their mass every 10 million years or so. If the dwarf galaxies continue to develop this way, they could each grow by a factor of four — which some theoretical models predict. "The implication is that many, if not most, of the stars in dwarf galaxies in the present-day universe form in the kind of bursts we see," says study leader Arjen van der Wel of the Max Planck Institute for Astronomy in Heidelberg, Germany.

The CANDELS team can't tell from its data if these galaxies' growth would continue to develop after the point in time it studied, and this information is still needed to probe how dwarf galaxies grow.

9 Curiosity tastes martian dust



NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA

The Curiosity rover used parachutes and a "Sky Crane" for a safe landing August 5/6. The High Resolution Imaging Science Experiment aboard the Mars Reconnaissance Orbiter captured this picture of the rover and its deployed parachute when it was about 2 miles (3.2 kilometers) above the Red Planet's surface.

8 Base of black hole's jet spied

Extremely dense supermassive black holes likely lie at the centers of all galaxies, and some of them spew jets of high-energy radiation. Such a black hole draws nearby gas into an "accretion" disk surrounding the dense object. Any material that falls past the black hole's event horizon is beyond the point of no return. A black hole also has an "innermost stable circular orbit" (ISCO); this is a distance outside of which the object's gravity doesn't overwhelm and thus material can still escape the eventual fate of the event horizon.

Astronomers think that a black hole's powerful magnetic field can collimate some of the material just outside the ISCO and launch jets perpendicular to the accretion disk. Some researchers question if the object's intrinsic rotation affects jets as well. Unfortunately, scientists haven't been able to observe the regions close enough to a supermassive black hole to verify predictions.

But in 2012, a group using an array of four radio dishes spread

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NASA/JPL-CALTECH/MSSS

Curiosity's color-enhanced 360° view of Bradbury Landing, with Mount Sharp about 12 miles (20 kilometers) away, appears as it would under Earth's skies.

The Mars Science Laboratory's seven minutes of terror became the engineering achievement heard 'round the world August 5/6 as Curiosity landed safely on the Red Planet. The most complicated landing ever on another world went smoothly, and the rover ended up just 0.9 mile (1.5 kilometers) from its target inside the 96-mile-wide (154km) Gale Crater.

The landing's complexity arose because Curiosity is 2,000 pounds (900 kilograms) and entered the martian atmosphere with a speed of about 13,200 mph (21,240 km/h). Because of its large mass, the rover could not land on just air bags, as the smaller Mars Exploration Rovers Spirit and Opportunity had done in 2004. Instead, Curiosity's descent included parachutes and a "Sky Crane" to touch down at 1.7 mph (2.7 km/h). Events went as planned.

The rover then underwent testing to ensure that the data communications antennas, its extendable arm, wheels, laser, and all other systems were operating safely. After about one month of testing, Curiosity began its exploration of Gale Crater with a discovery of rounded pebbles, indicating a streambed of once-flowing water. The rover went on to visit Glenelg, an area with three intersecting types of terrain.

The rover next will take nearly one year to reach the base of Mount Sharp — the 3-mile-high (5km) mountain of sedimentary rock in the crater's center. Curiosity covers about a football-field-distance on each day's drive if it doesn't encounter any obstacles. Along the way, the rover will occasionally sample soil and rock.

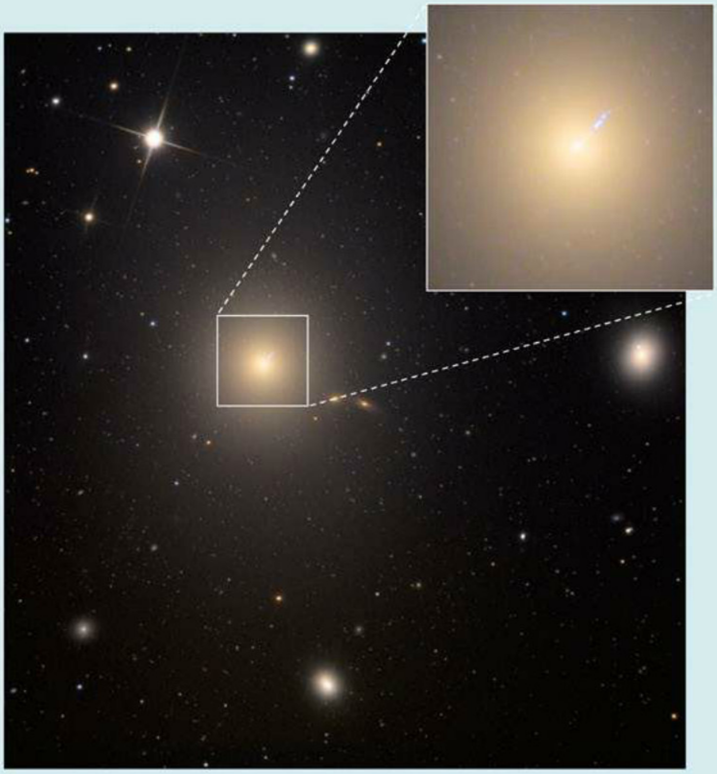
Once at the mountain, the rover needs to reach a few hundred meters' elevation to sample the types of materials that scientists want — clay and sulfate-bearing rocks, which hold information about the Red Planet's water history. Its 10 instruments will help Curiosity make more-detailed measurements than any other rover that's landed on the Red Planet.

across Earth may have changed that. It observed the elliptical galaxy M87 that lies about 55 million light-years from our planet. The galaxy harbors a supermassive black hole about 6.2 billion times the Sun's mass at its center crammed into a space about five times the solar system's width. And this behemoth has a jet that extends hundreds of thousands of light-years.

The array, which astronomers call the Event Horizon Telescope (EHT), observed the central region of M87 for three consecutive days at a wavelength of 1.3 millimeters — firmly in light's microwave regime. It could image details just 40 microarcseconds across (the Full Moon's width is about 1.8 billion microarcseconds).

The EHT team reported in late September that by combining the array's high resolution and computational modeling, it determined that the base of M87's jet lies at the ISCO, about 5.5 times the event horizon's radius. While it found the jet's origin, the team isn't yet sure how much a black hole's spin affects radiation jets.

Some of these dense objects spin in the same direction as their accretion disks, some in the opposite direction, and others don't spin at all. According to the study, the EHT data seem to rule out rotation in opposite directions as a contributor to jet formation; however, the team agrees that more observations, with high resolution, will help answer the question. It does plan on adding radio dishes to the array to further this project along with the EHT's main goal: image a black hole's event horizon and surrounding distortions of light (caused by the object's extreme gravity), which would give astronomers the first direct evidence that black holes exist.



Astronomers used an Earth-sized radio array to resolve the base of M87's high-energy jet, seen here in visible light. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

7 DIY funding ramps up

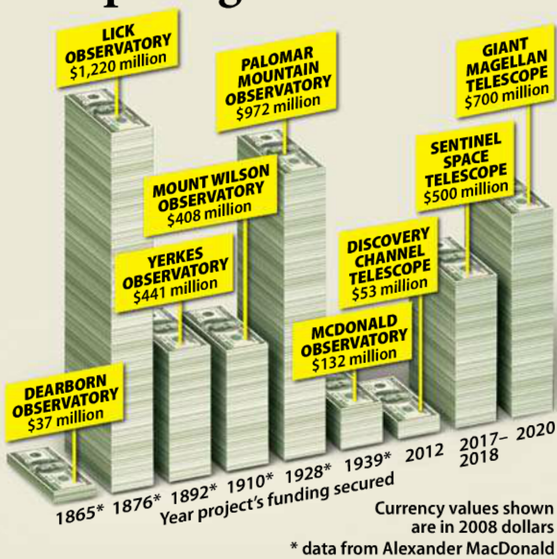
Some of this year's headlines talked not about discoveries made from telescopes, but instead about the instruments' funding. In April, the organization behind the future 24.5-meter Giant Magellan Telescope announced it would not apply for funds from the U.S. National Science Foundation. (That funding could have garnered $1.25 million in five years.) In May, the Discovery Channel Telescope, a 4.3-meter instrument run by Lowell Observatory in Flagstaff, Arizona, saw first light — a project that received no state or federal funding. Then in June, the B612 Foundation revealed its plans to develop and build Sentinel, a privately funded space telescope that would be the first of its kind.

Initially, the thought of organizations opting out of funding for their planned expensive instruments might sound crazy. But it's actually a return to the way such projects used to be financed. The grand observatories of the past — Lick in California, Yerkes in Wisconsin, Mount Wilson in California — all existed because of wealthy individuals. No government organization funded them.

Perhaps the board members of the Giant Magellan Telescope, Sentinel, and the Discovery Channel Telescope have concluded that science funding in this country is ever more rare and difficult to obtain. (Plus, with a large portion of NASA's budget going toward the upcoming James Webb Space Telescope, there's less for smaller projects.)

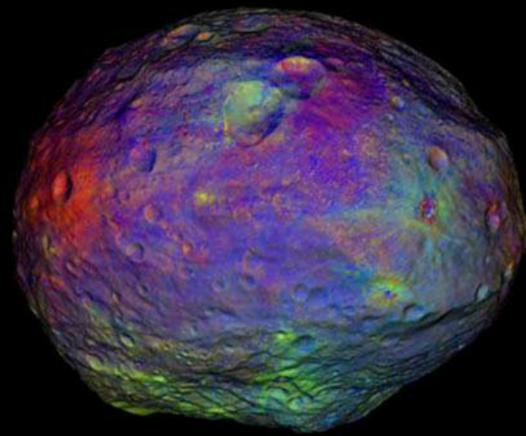
To top off the funding oddities, the U.S. National Reconnaissance Office in charge of America's intelligence satellites gifted to NASA two Hubble-class telescope shells. While these were free, the space agency and science institutions still will need to outfit the telescopes with instruments, but they haven't yet allocated funding to do so.

Comparing cost



ASTRONOMY: ROEN KELLY

Privately funded astronomical instruments are becoming more popular; this used to be the way observatories were financed.



Vesta's surface holds a range of minerals. In this image, each color represents a different material; green shows iron, but scientists aren't sure what minerals the other colors indicate. NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA/PSI

6 Dawn uncovers Vesta's secrets

NASA's Dawn spacecraft arrived at Vesta, one of the largest asteroids in the solar system, July 17, 2011, and spent more than a year examining it. Over that time, scientists have learned that the object appears more planet-like than asteroid-like, with a layered composition consisting of a crust, mantle, and iron core.

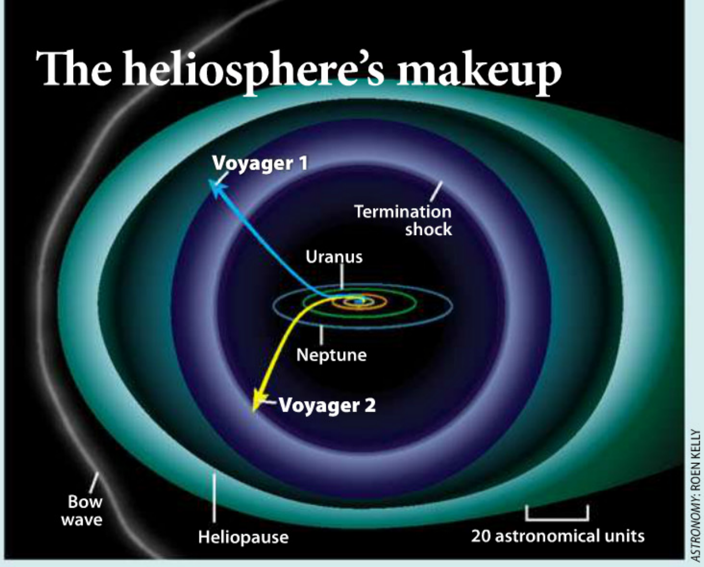
Scientists determined Vesta's mass from the way Dawn reacted to the asteroid's gravity as it orbited the object. That force changes depending on the rotation of the asteroid and how the mass is distributed. These measurements also allowed scientists to determine the size of the iron core — 136 miles (220 kilometers) wide — and conclude that Vesta's interior is layered.

While at the asteroid, Dawn captured more than 4,700 images and nearly 9 million visible and infrared spectra to uncover the nature of this planetary building block. Before the craft arrived at Vesta, scientists' best view of the asteroid was a small fuzzy photograph from the Hubble Space Telescope. From that image, they knew that the asteroid's south pole had experienced a huge past collision that created the Rheasilvia Basin, which spans nearly the asteroid's entire width. But Dawn showed them the extent of the crater: about 310 miles (500km) wide and 12 miles (19km) deep, and covering nearly half of another, older impact basin. The newly discovered impact scar, named Veneneia, spans nearly 250 miles (400km) with a depth of roughly 7 miles (12km). Dawn scientists determined that an impact created Veneneia about 2 billion years ago, and another huge impact resulted in Rheasilvia just 1 billion years ago, which is more recent than expected. These two collisions essentially erased all the cratering history at Vesta's south pole.

Other instruments aboard Dawn measured the asteroid's climate and mapped its surface brightness. Vesta's temperature ranges from –10° Fahrenheit (–23° Celsius) down to at least –150° F (–100° C) in the shadows (the lowest temperature Dawn can measure). Vesta's surface brightness covers a wider range than that seen on any other asteroid, although scientists aren't sure what causes the differences. They suggest that the darkest material may have been excavated by large impacts, deposited by slow-moving incoming collisions, or a mixture of both.

Dawn parted ways with Vesta on September 5 and is heading to its next target, the larger asteroid Ceres, where it will arrive in February 2015.

5 IBEX reveals a softer edge



The Sun's protective heliosphere moves through the Milky Way's interstellar material slower than expected and thus has a "bow wave" outer structure.

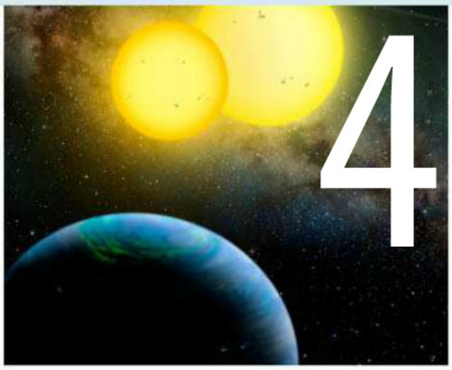
In the Milky Way, the space between stars is not empty but instead holds gas and dust. As the Sun moves through this interstellar medium, the solar wind of charged particles along with the Sun's magnetic field create a cavity around our star called the heliosphere. Astronomers have long thought that three layers — the termination shock, heliopause, and bow shock — compose this bubble.

In 2008, scientists launched the Interstellar Boundary Explorer (IBEX) to measure the heliosphere's properties. While most detectors see light, IBEX directly samples the neutral particles from the interstellar medium that pass through the Sun's heliosphere.

The spacecraft gave astronomers a surprise: The Sun doesn't plow through the galaxy as fast as expected, a fact that has implications for the heliosphere's outer structure. As our star's protective magnetic bubble rams into galactic material, it slows the Sun's cavity, similar to the formation of a bow shock when a supersonic jet compresses and pushes air aside.

IBEX data earlier this year showed that the Sun moves relative to the interstellar medium 7,000 mph (11,300 km/h) slower than the expected 59,000 mph (95,000 km/h). "That might not seem like a huge difference, but it translates to a quarter less pressure exerted on the boundaries of the heliosphere," says IBEX principal investigator David McComas of the Southwest Research Institute in San Antonio, Texas. "There's a very different interaction, a much weaker interaction, than previously thought."

Scientists say that instead of the predicted bow shock, the third layer is more like a bow "wave," and thus the Sun's wind and magnetic field create a gentler compression as our star moves through the galaxy.



Planets orbiting binary stars, like the system in this illustration of Kepler-35b, were one of many unexpected categories of extrasolar worlds discovered this year. LYNETTE COOK

4 Exoplanets discovered in surprising situations

Eight hundred and forty-three — that's how many confirmed planets orbit other stars, at the time of this writing. Every year, the number increases more rapidly, and many of these worlds live in environments where astronomers didn't expect to find any.

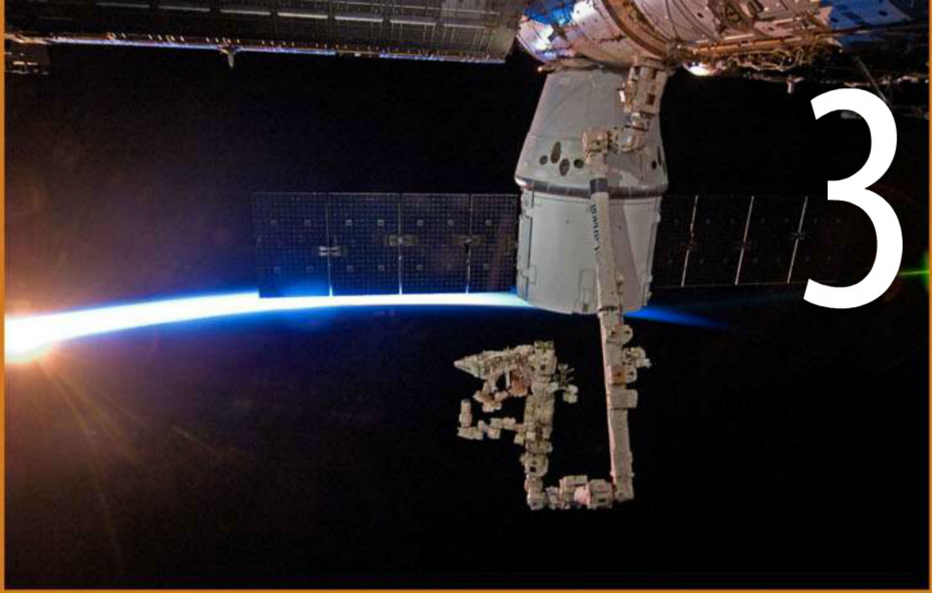
The extrasolar planet haul is largely due to NASA's Kepler telescope, a workhorse that stares at more than 150,000 stars looking for slight dips in brightness. Such a change could indicate a planet passing in front of, or transiting, the star. The scope must observe at least three similar dips in light to indicate a possible world. Then, astronomers use other telescopes to investigate each candidate object further to determine if it's an exoplanet or a false positive.

Kepler's primary goal is to find Earth-like worlds orbiting within their stars' habitable zones (HZ) — the regions around those stars that have the right temperature to allow surface water to exist on the planets — and it continues to inch toward achieving this goal. So far, the closest world to an Earth-twin, named Kepler-22b, spans just 2.4 times our planet's diameter and orbits within its star's HZ. Its host sun contains about 97 percent of the Sun's mass and lies 620 light-years from Earth.

But astronomers also have found worlds that live in settings they didn't expect, like stellar pairs. Scientists have found a handful of "Tatooine" worlds — named after the two-sun planet in *Star Wars*. Surprisingly, many of these extrasolar worlds should remain in stable orbits around their double stars for millions of years. They also spied two planets orbiting a binary star, and amateur astronomers spotted a world circling two suns in a four-star system.

Then there are two planets that orbit a star made up of little more than hydrogen and helium. Scientists had long thought a star needed to contain elements heavier than helium — which astronomers call "metals" — to host planets. So, how could a 0.78-Jupiter-mass world and a 2.93-Jupiter-mass planet have formed in such an environment? Researchers aren't sure.

Other finds have included a planet with an atmosphere of mostly dense water vapor, worlds disintegrating due to their close proximities to their stars, two planets that survived their sun's evolutionary red-giant stage, and a world orbiting Alpha Centauri B in the star system nearest the Sun. And with more than 2,000 candidate exoplanets from Kepler, expect more surprises.



3 Commercial craft takes historic flights

When SpaceX's Dragon capsule berthed with the International Space Station in May, it made history as the first privately developed craft to do so. NASA

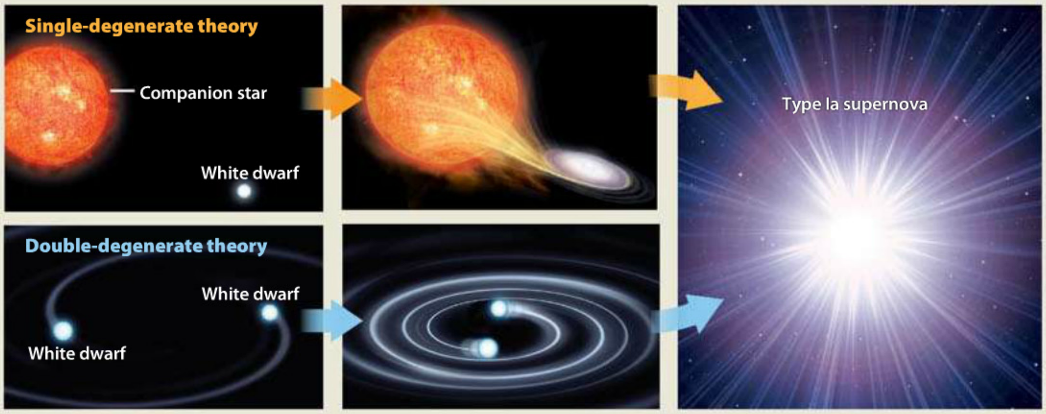
Last year's top story focused on the end of NASA's Space Shuttle Program and the gap it left in human space exploration. But 2012 showed the future of spaceflight — and how private companies will be major players.

On May 22, Space Exploration Technologies (SpaceX) launched its Dragon capsule atop the company's Falcon 9 rocket from Cape Canaveral Air Force Station in Florida. Three days later, the craft berthed with the International Space Station (ISS) — becoming the first commercial spacecraft to do so. During the five days Dragon was attached to the station, astronauts transferred more than 1,100 pounds (500 kilograms) of supplies from the capsule into the ISS. Dragon splashed down safely in the Pacific Ocean on May 31.

This was the company's second demonstration flight as part of an agreement with NASA, signed in 2006, to develop

2 Astronomers question how a star blows up

Creating a type Ia supernova



A type Ia supernova can result from two different paths, and more discoveries in 2012 questioned whether the energy emitted during the explosion is consistent. The concern has big consequences: Such supernova measurements have been used to measure the universe's accelerating expansion. *ASTRONOMY*: ROEN KELLY

A specific kind of exploding star, called a type Ia supernova, results from a remnant white dwarf stealing material from a companion sun and exploding once it reaches a certain mass. Scientists are questioning what type of star is donating that material, and evidence shows that type Ia supernovae may be the result of two separate methods — which could mean the explosions emit varying amount of energies. That's cause for concern.

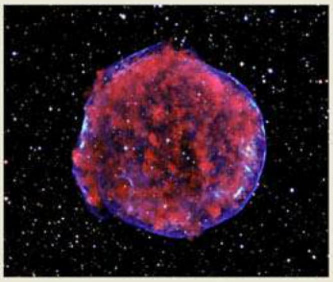
In the "single-degenerate" model, the white dwarf collects gas from a partner until it reaches about 1.4 times the mass of the Sun. It then explodes, leaving behind its companion. The consistent mass produces the same energy and luminosity, which means that if you see a type Ia supernova in a distant galaxy, you can compare the collected signal to the expected brightness to determine how far away the host galaxy is. This is the method cosmologists used to discover that the universe's expansion is speeding up. And in 2012, they won the Nobel Prize in physics for this finding.

But the "double-degenerate" theory follows that two white dwarfs collide in explosive fashion. Those stellar remnants may not be the same size in every explosion, meaning there's no way to standardize the energy seen from one to the next.

Two teams of astronomers this past year searched images looking for the leftover companions to the long-dead white dwarfs of two type Ia supernovae: supernova remnant 0509–675 (400 years old) and SN 1006 (1,000 years old). The scientists calculated how far companion

the capability to carry cargo to and from the ISS. Then, on October 8, SpaceX launched its first of many regular supply runs to the station. The ISS captured the capsule October 10 for an 18-day stay.

In August, NASA also awarded a $440 million contract to the company to build the space shuttle successor to return Americans to Earth orbit. SpaceX intends to launch its first manned flight by 2015 — a big goal indeed, but given the company's track record, one it likely can reach. Elon Musk, CEO and chief designer, founded SpaceX just 10 years ago, and in that time it has developed rocket launchers and a ferry vehicle. We will certainly hear more about SpaceX's successes in the years to come.



X-RAY: NASA/CXC/RUTGERS/K. ERIKSEN, ET AL.; OPTICAL: DSS

The Tycho supernova remnant is the result of a type Ia supernova. Scientists have spotted evidence of the exploding white dwarf's donor companion still within the remnant.

stars could have moved since the explosions, but they found no remaining suns in either case. In the SN 1006 search, the team also looked for the characteristic radiation of a companion and turned up empty. Thus, both supernovae likely resulted from white dwarfs merging.

How many other previously observed type Ia supernovae originated from the double-degenerate method instead of a giant star donating material to its white dwarf companion? And does this call into question the hundreds of distant measurements of type Ia supernovae across the universe? Perhaps.

1 Physicists detect long-sought particle

The Compact Muon Solenoid at the Large Hadron Collider in Europe is one detector that found a new particle that has characteristics consistent with the long-sought Higgs boson. CERN/CLAUDIA MARCELLONI

Physicists describe all ordinary matter and the forces acting upon it using the so-called standard model. But, in the four decades they've used this theory, they hadn't been able to experimentally explain what gives each particle its rest mass, which is the mass a particle has when it's not moving.

Scientists hypothesize that each particle in the standard model interacts with the "Higgs field" to obtain mass. (For example, an electron interacts with the Higgs field and thus has mass, whereas a photon doesn't interact with it and has no mass.) This field also has a force carrier, called the Higgs boson. But this particle remained undetected — the last missing piece of physics' standard model.

Then, on July 4, physicists with the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) announced that they had found a new particle, and its preliminary characteristics are consistent with the Higgs. After crunching data from two LHC experiments — A Toroidal LHC Apparatus (ATLAS) and the Compact Muon Solenoid (CMS) — in 2011 and 2012, researchers reported the signal of a particle near an energy of 126 billion electron volts (eV). (An eV is a unit of rest mass energy; one electron has a rest mass energy of 511,000 eV.)

To verify a signal as a discovery in physics, the analysis has to yield a "five-sigma result" — that's statistics speak for only a 1 in 1.7 million chance that the signal is an error. Researchers have verified the new particle to 5.9 sigma, or just a 1 in 1.7 billion chance of an error. While they're sure they have found a previously undetected particle, they can't say with certainty that it's the Higgs. As the ATLAS collaboration writes in a September 17 paper in *Physics Letters B*, "Although these results are compatible with the hypothesis that the new particle is the Standard Model Higgs boson, more data are needed to assess its nature in detail."

And if this discovered particle is something else entirely, researchers will have opened another door in particle physics, thus continuing the ever-constant scientific search to understand the universe. But it's looking more likely that scientists have discovered the long-sought Higgs boson.

NEWS STORIES TO WATCH IN 2013

- Look for Comet C/2012 S1 (ISON); it could be one of the brightest comets ever seen.
- The Curiosity rover will reach the Red Planet's Mount Sharp and sample martian soil and rock along the way.
- India plans to launch an unmanned spacecraft to Mars in November.
- The global economy is impacting science funding — what projects will be cut?
- The European Space Agency will release the first data set from the Planck mission's investigation of the cosmic microwave background, the Big Bang's relic radiation.

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Voyager's "new" solar system

Two planetary spacecraft embarked on a grand tour that revealed rings around Jupiter, volcanoes on Io, a planet-sized storm on Neptune, and much more. **by Michael E. Bakich**

These are the voyages of two spacecraft named Voyager. Their five-year mission: to explore strange new worlds; to seek out new moons and new geologic processes …

They were relatively modest spacecraft upon which engineers bestowed relatively modest missions and short life spans. So, when NASA launched Voyager 1 and Voyager 2 from Cape Canaveral, Florida, in the summer of 1977, no one could have guessed that those unassuming spacecraft would come as close as any that humanity has launched to fulfilling the dream of *Star Trek*'s *Enterprise* — discovery.

Five years was just the start

Originally, the space agency tasked the Voyagers with conducting close-up studies of Jupiter and Saturn. While visiting those worlds, they would compile data on magnetic fields, the Sun's influence, and the nature of Saturn's rings. As a bonus, the spacecraft would fly by the two planets' largest moons. To accomplish all this, engineers built into them a generous (for the 1970s) five-year lifetime.

As the mission went on, it achieved all of its objectives and more. While the spacecraft flew from one world to the next, project scientists at the Voyagers' home at NASA's Jet Propulsion Laboratory in Pasadena, California, reprogrammed them with greater capabilities than they had when they left Earth.

Then came the big news. By carefully tweaking Voyager 2's flight path, a flyby of both of the outer giant planets, Uranus and Neptune, was possible, and with all instruments still operating. As you might imagine, the treasure-trove of scientific data that the spacecraft could mine from such an addition proved irresistible.

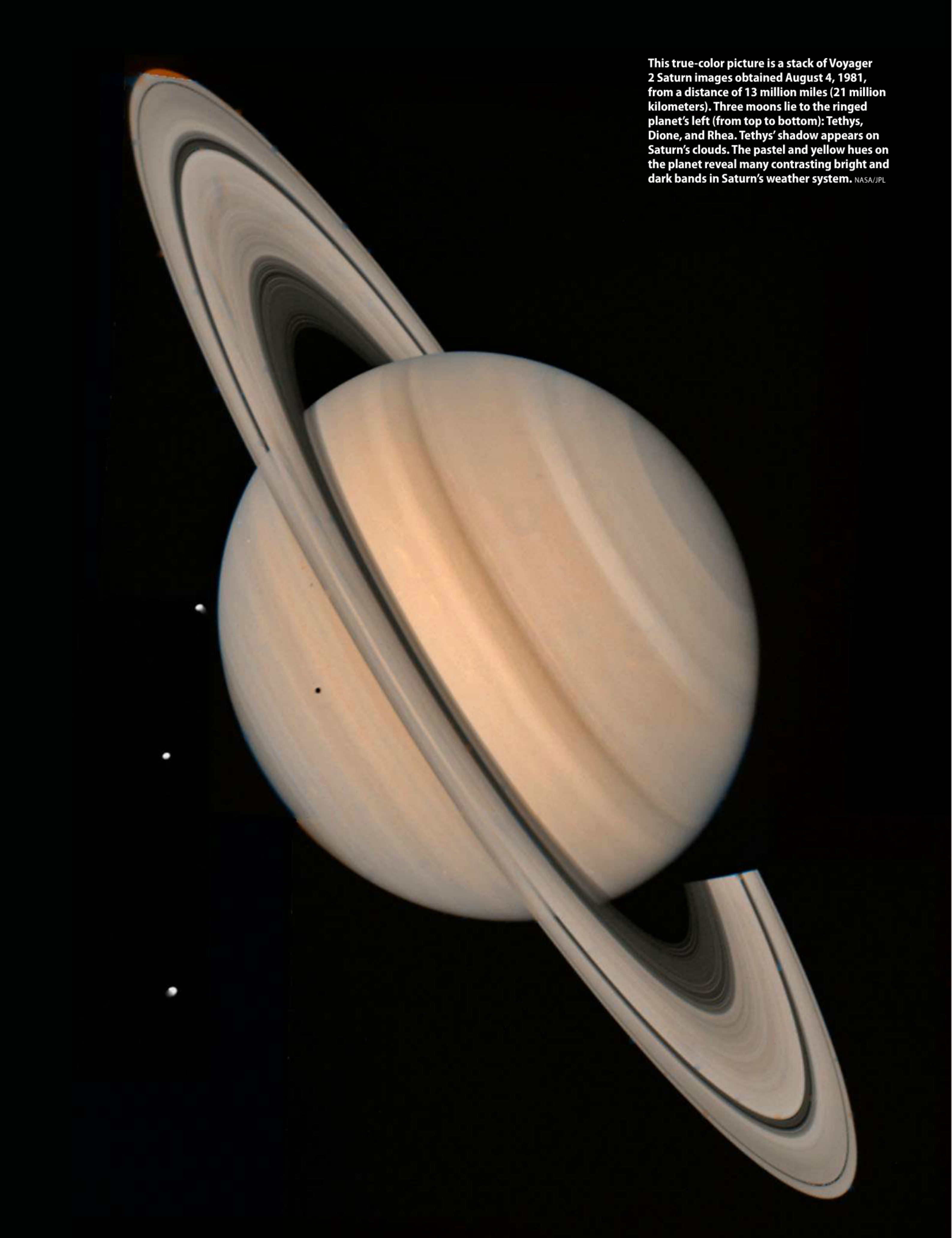
Their two-planet mission doubled to become four. Their projected five-year lifetimes stretched to 12 to include the Neptune encounter in 1989. And even that date would become early history. Imagine the surprise of project scientists back then if they could have looked forward to 2013: Both Voyagers are more than halfway through their fourth decade of continuous operation.

This view of Jupiter's Great Red Spot shows greatly exaggerated colors, given to it by Voyager scientists. By enhancing subtle variations in both color and shading, researchers can better trace the wind patterns within this giant storm. NASA/JPL

One surprise after another

The Voyager spacecraft made too many discoveries to list here. So, as an homage to Liz Kruesi's "Top 10 space stories" (page 22), here are Voyager's Top 10 discoveries.

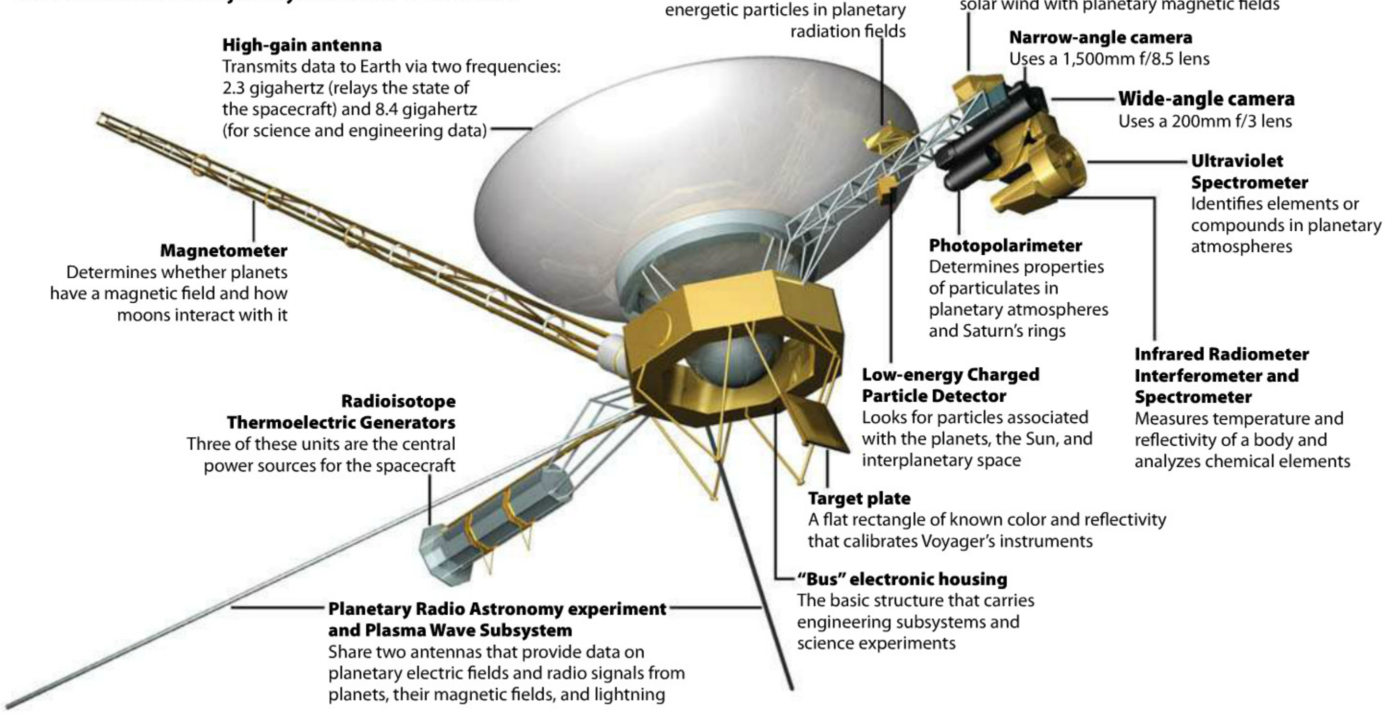
1) Volcanoes on Jupiter's moon Io. This was the biggie. While processing an image Voyager 1 took March 8, 1979, navigation engineer Linda Morabito discovered a 190-mile-tall (300 kilometers) feature



This true-color picture is a stack of Voyager 2 Saturn images obtained August 4, 1981, from a distance of 13 million miles (21 million kilometers). Three moons lie to the ringed planet's left (from top to bottom): Tethys, Dione, and Rhea. Tethys' shadow appears on Saturn's clouds. The pastel and yellow hues on the planet reveal many contrasting bright and dark bands in Saturn's weather system. NASA/JPL

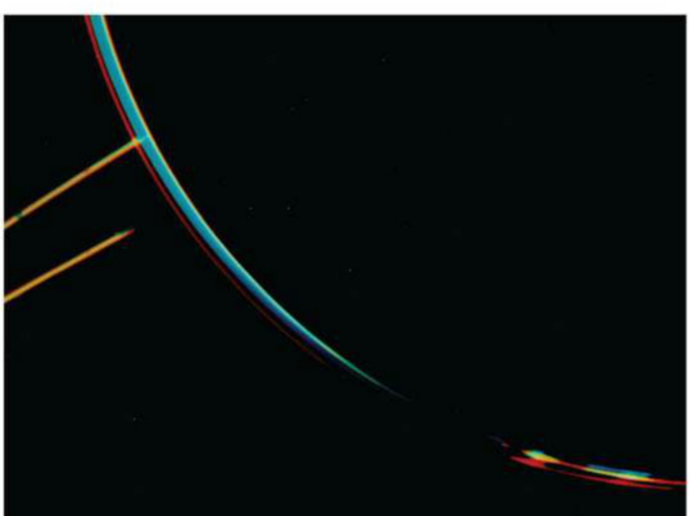
Voyager's tools to study the planets

The instrument package aboard both Voyagers may seem crude by today's standards, but it was state of the art when the two spacecraft embarked on their journeys in the late 1970s. NASA/JPL

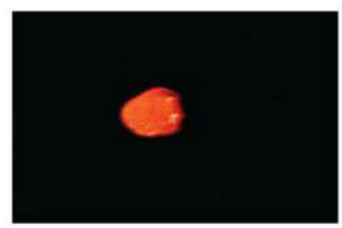


along the large satellite's edge. She initially thought it was another moon, but it turned out to be a plume from an active volcano. Astronomers subsequently learned that Io's interior was in turmoil: It literally was stretching this way and that because Jupiter's gravity affects Io differently when the moon is closest and farthest from the planet. Such tidal (in this sense, gravitational) interaction creates intense heating due to friction. This results in Io showing 100 times as much volcanic activity as on Earth.

2) Jupiter's turbulent atmosphere. After three centuries of watching the giant planet's cloud bands and (supposedly tranquil) Great Red Spot, Voyager 1 gave scientists an up-close look. They saw dozens of interacting hurricane systems, some as large as planets. Careful processing of images revealed the Great Red Spot itself to have layers of complex activity. The Voyagers showed that the spot lies 5 miles (8km) above the surrounding clouds, and time-lapse movies confirmed its counterclockwise rotation.



Voyager 2 discovered Jupiter's faint ring system from a range of 900,000 miles (1,450,000 kilometers). This image, taken in Jupiter's shadow through orange and violet filters, shows the rings as two light-orange lines protruding from the left toward the planet's edge. The lower ring image was cut short by Jupiter's shadow on it. NASA/JPL

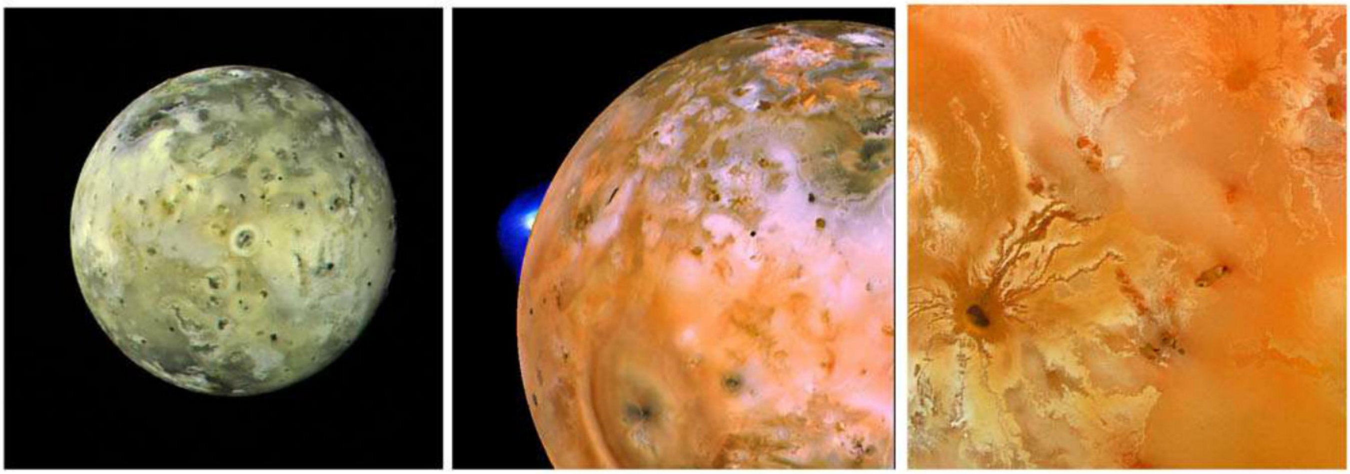


Jupiter's moon Amalthea held an amazing secret: Its color results from Io's volcanoes blasting reddish material into space, which eventually falls on Amalthea. Voyager 1 took this shot from 255,000 miles (425,000 kilometers) on March 4, 1979. NASA/JPL

3) An ocean within Europa? As the two spacecraft flew by the third-largest jovian moon, its icy crust showed a dizzying series of intersecting cracks. Calculations indicated the possibility of a liquid ocean deep beneath the ice. Such a feature can exist because of the tidal interaction between the moon and Jupiter. Europa's orbit is closer to circular than Io's, so the internal heating wouldn't be great enough to create volcanoes. It would, however, be enough to melt vast quantities of ice.

4) The Io torus. Voyager 1 found a thick ring of ionized sulfur and oxygen shed by Io that inflates Jupiter's giant magnetic field. The material originates within the moon's many volcanoes, some of which are so powerful that they erupt it directly into space. And there's an astounding byproduct of that activity: Through the eons, some of that material ejected by Io has fallen on the tiny moon Amalthea. The continual raining-down of sulfur from space has changed Amalthea's original dark color to red.

5) Saturn's ring structure. Before 1980, astronomers recognized fewer than half a dozen rings around Saturn. But the



Io shocked astronomers when they realized it was the first solar system body other than Earth to show active volcanism. Voyager 1 took the left image approximately 500,000 miles (800,000 kilometers) from the moon. From 340,000 miles (490,000km), it snapped the center image, which shows an enormous volcanic eruption from a plume scientists called Loki silhouetted against dark space. The right image, taken when the spacecraft was 77,100 miles (128,500km) from Io, shows a surface colored by sulfur deposits that volcanoes heated to different temperatures. NASA/JPL

cameras on the Voyagers showed that each ring has subdivisions consisting of ringlets (thin rings) and gaps (narrow separations between rings or ringlets). In addition, Voyager 1 discovered that the enigmatic F ring — discovered the year before by the Pioneer 11 imaging team — has two small "shepherding" satellites, Pandora and Prometheus, whose combined gravity keeps it in place.

6) Titan's atmosphere. NASA scientists made Saturn's largest moon a prime target for Voyager 1. The spacecraft showed Titan has a nitrogen atmosphere that produces a surface pressure 45 percent greater than on Earth. Voyager data hinted at the possibility (later confirmed) that this satellite experiences clouds of methane and other hydrocarbons and that rain falling from those clouds creates lakes of liquid methane on the surface.

7) Neptune's Great Dark Spot. As Voyager 2 approached Neptune, scientists identified a gigantic dark feature. Dubbed the Great Dark Spot, researchers were at a loss to explain how such a storm could form given the small amount of energy Neptune receives from the Sun. Further study showed that the Great Dark Spot and similar features observed since Voyager 2 passed by are cyclones that exist as holes in the planet's upper atmosphere.

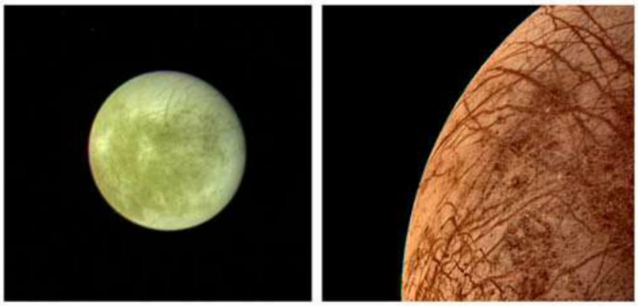
8) Neptune's supersonic winds. If the Great Dark Spot was a surprise, the discovery of the fastest winds in the solar system in the atmosphere of the most distant planet was a stunner. Voyager 2 measured wind speeds of 1,100 mph (1,600 km/h) above Neptune. Because the planet radiates 2.6 times as much energy as it receives from the Sun, researchers think the decay of radioactive elements deep within Neptune powers the currents.

9) Geysers on Triton. In addition to observing clouds and hazes in the thin atmosphere of Neptune's largest satellite, Voyager 2 found evidence of cryovolcanoes (those that erupt volatiles such as water, ammonia, and methane instead of molten rock). These active geysers within the moon's southern polar cap spew dust-laden nitrogen up to 5 miles (8km) above the surface, which lies in perpetual cold at a temperature of 37 kelvins (–393° Fahrenheit).

10) The edge of the solar system. The Voyager spacecraft didn't stop working after their planetary encounters. As early as

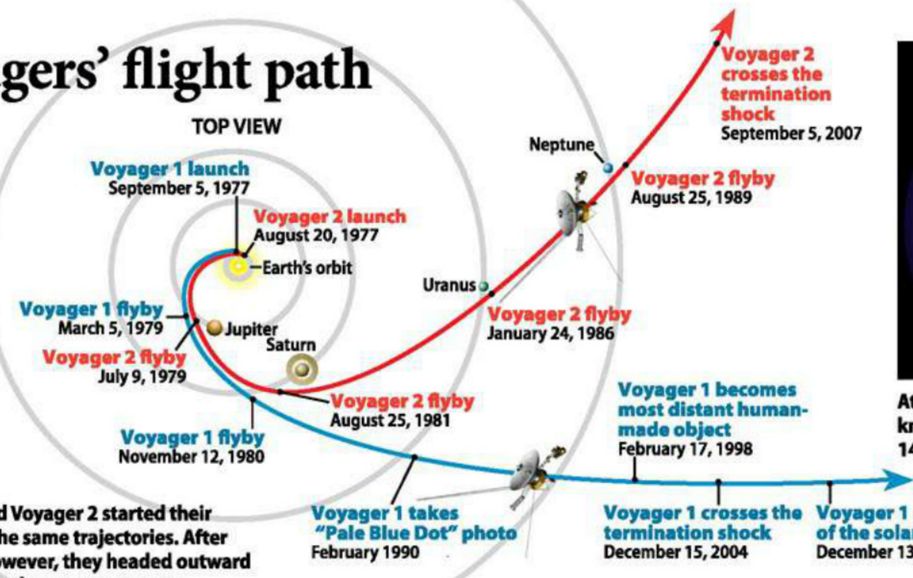
Michael E. Bakich *is an* Astronomy *senior editor who first presented Voyager's discoveries to the public while working in various planetaria during the exciting time both spacecraft were exploring the outer planets.*

This false-color picture of Callisto, taken by Voyager 2 on July 7, 1979, at a range of 677,000 miles (1,095,000 kilometers), shows the most heavily cratered surface of any of Jupiter's four large satellites. The bright areas are ejecta thrown out by relatively young impact craters. A large ringed structure, probably an impact basin, lies at the upper left. NASA/JPL

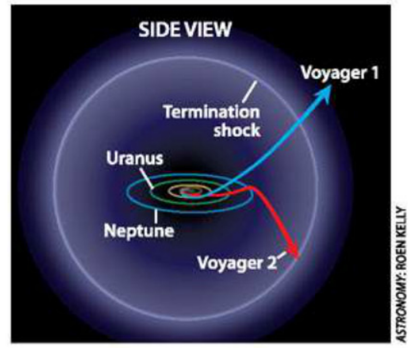


Voyager 1 snapped Europa (left) on March 4, 1979. Scientists wondered about the linear structures — some of them more than a thousand kilometers long — that crisscross the surface. Voyager 2 solved the mystery July 9, 1979, when it took the image on the right. They reasoned that Europa has a crust of ice some 60 miles (100 kilometers) thick that overlies the silicate crust. The complex streaks indicate that the crust fractured and materials from below have filled the cracks. NASA/JPL

Voyagers' flight path



Voyager 1 and Voyager 2 started their journeys on the same trajectories. After four years, however, they headed outward on different paths. ASTRONOMY: ROEN KELLY



ASTRONOMY: ROEN KELLY

At its 2012 speed of 38,200 mph (61,400 km/h), Voyager 1 will require another 14,000 years to travel 1 light-year.

Saturn's rings and their shadows appear in this Voyager 1 image taken November 13, 1980, at a distance of 930,000 miles (1,500,000 kilometers) as the spacecraft was leaving Saturn. The dark band cutting through the planet's crescent is the shadow from the rings above. Scientists overexposed the photo to bring out detail in the rings, so the crescent appears artificially brighter. NASA/JPL

Saturn's A ring was the target of Voyager 2's camera when the craft stood about 1.7 million miles (2.8 million kilometers) from the planet. This photo covers a width of approximately 9,300 miles (15,000km). The thick black line is the Encke Division, a prominent gap in the A ring. Near the top of the frame sits Pandora, a satellite then only known by its discovery number, 1980S27. NASA/JPL

Saturn's B ring showed an odd feature when Voyager 2 imaged it from a distance of 2.5 million miles (4 million kilometers). Evident here are its numerous "spoke" features (in the B ring). Scientists now think their sharp, narrow appearances suggest short formation times and that they consist of microscopic dust particles suspended above the main ring system by electrostatic repulsion. NASA/JPL

GRAND TOUR OF THE SOLAR SYSTEM

In 1964, American aerospace engineer Gary Flandro, at the Jet Propulsion Laboratory in Pasadena, California, conceived an ambitious plan to launch unmanned probes to the outer planets using a minimum of fuel and time. His so-called "Grand Tour" depended on an alignment of Jupiter, Saturn, Uranus, Neptune, and Pluto that occurs every 175 years. According to Flandro, a probe launched toward Jupiter could use that planet's gravity as a slingshot to help it reach more distant planets.

The original mission called for four probes: Two would fly by Jupiter, Saturn, and Pluto; the other two would encounter Jupiter, Uranus, and Neptune. NASA budget cuts unfortunately doomed the Grand Tour missions in 1972. The agency, however, added many of their elements to the Voyager program.

The space agency first used a gravity-assist technique with its Mariner 10 probe to Mercury. Launched in 1973, the spacecraft used Venus' gravity to put it on the right course to the innermost planet. Later, a similar maneuver reduced Voyager 2's flight time to Neptune from 30 years to 12.

Space scientists now specifically regard Voyager 2's mission to four planets as the Grand Tour. NASA could have sent Voyager 1 to Pluto after the craft encountered Saturn but instead put it on a trajectory that brought it close by the ringed planet's largest moon, Titan. *— M. E. B.*

2014, Voyager 1 may pass our solar system's edge — a boundary astronomers call the heliopause — where the interstellar medium stops the solar wind. In essence, the strength of the solar wind at this distance isn't powerful enough to overcome the stellar winds of nearby stars. Voyager 1 crossed another border, the termination shock, where the solar wind abruptly slows to subsonic speed, in 2004. Voyager 2 followed in 2007. When each spacecraft crosses the heliopause, their Voyager Interstellar Mission will commence.

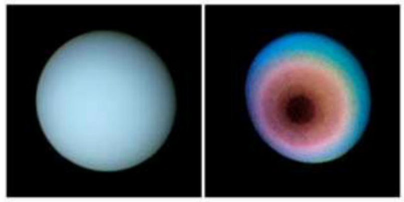
A new horizon

As of October 18, 2012, Voyagers 1 and 2 lay 11.41 billion miles (18.36 billion km) and 9.29 billion miles (14.95 billion km) from Earth, respectively. And the craft are still making news. Voyager 1 recently crossed into a zone astronomers call the stagnation region. There, at the boundary of interstellar space, the solar wind is less intense but the magnetic field measures twice as strong.

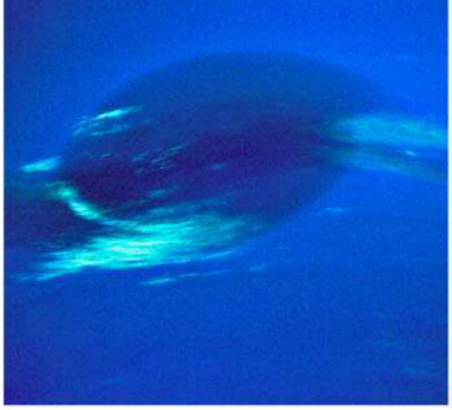
"Voyager tells us now that we're in the outermost layer of the bubble around our solar system," says Ed Stone, Voyager project

The "Pale Blue Dot" is a photograph of Earth taken by Voyager 1 from a distance of 3.7 billion miles (6 billion kilometers). The spacecraft took this shot between February 14 and June 6, 1990, at the request of American astronomer Carl Sagan. NASA/JPL

Saturn's moon Mimas reminded mission scientists of the Death Star from the movie *Star Wars*. Mimas' largest feature is Herschel, an 81-mile-wide (130 kilometers) impact crater whose central peak rises 3.7 miles (6km) above the crater floor. NASA/JPL



Voyager 2's narrow-angle camera shot Uranus on January 10, 1986, when the spacecraft was 11 million miles (18 million kilometers) from the planet. The view focuses on the planet's pole of rotation, which lies just left of center. The left image shows Uranus as human eyes would see it from Voyager's vantage point. The second picture is a false-color view that reveals normally invisible details, including what could be a polar haze of smoglike particles. NASA/JPL



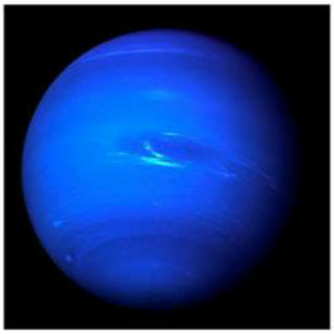
The Great Dark Spot was a major surprise at Neptune because scientists didn't think enough energy was present so far from the Sun to create such weather features. Voyager 2's narrow-angle camera took this image 45 hours before closest approach and at a distance of 1.7 million miles (2.8 million kilometers). The smallest structures measure 30 miles (50km) across. NASA/JPL

scientist and the mission's main spokesperson since 1972 at the California Institute of Technology in Pasadena. "Voyager is showing that what is outside is pushing back. We shouldn't have long to wait to find out what the space between stars is really like."

Voyager 1 is leaving the solar system, rising above the ecliptic (the plane of Earth's orbit) at an angle of about 35° and a rate of about 320 million miles (520 million km) per year. Meanwhile, Voyager 2 is also headed out of our planetary realm, diving below the ecliptic plane at an angle of about 48° and a rate of about 290 million miles (470 million km) per year.

Both spacecraft will continue to study ultraviolet sources among the stars and the boundary between the Sun's influence and interstellar space. The Voyagers are expected to return valuable data for at least another decade. NASA will maintain communications until the Voyagers' power sources can no longer supply enough electrical energy to operate critical subsystems.

This mosaic of Miranda includes frames obtained by Voyager 2 during its flyby of the uranian moon January 24, 1986. On Miranda, ridges and valleys of one region adjoin the boundary of the next. Both compressional (pushed-together) ridges and extensional (pulled-apart) faults form patterns. NASA/JPL



Voyager 2 found that Neptune's atmosphere contains 84 percent hydrogen, 12 percent helium, 2 percent methane, and small quantities of other gases. The high-altitude methane absorbs the red wavelengths from sunlight and reflects blue ones. That's why the planet appears blue. NASA/JPL

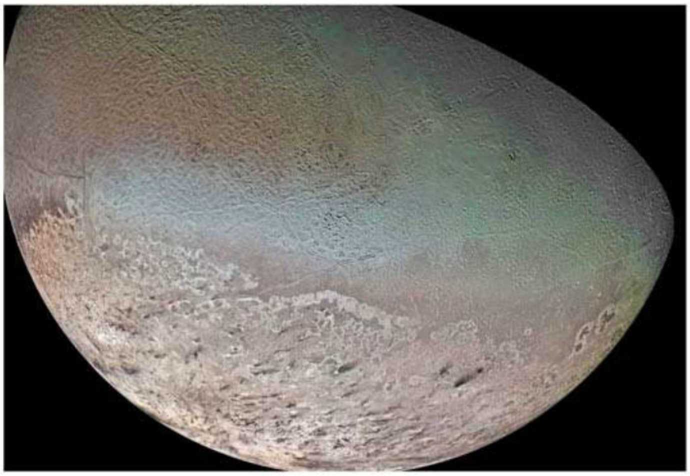
Contact?

Pioneers 10 and 11, which preceded Voyager, both carry small plaques identifying their time and place of origin for the benefit of civilizations that might encounter them. NASA, through a committee chaired by American astronomer Carl Sagan of Cornell University, placed a more ambitious message aboard the Voyagers.

The message rides through space on a phonograph record — a 12-inch (30.5 centimeters) gold-plated copper disk. It contains 115 images and a variety of natural sounds, such as those made by surf, thunder, birds, and whales. It also offers musical selections from different cultures and eras, and spoken greetings in 55 languages.

Sagan later noted that the Voyagers represented more to Earth than mere science: "The spacecraft will be encountered and the record played only if there are advanced spacefaring civilizations in interstellar space. But the launching of this bottle into the cosmic ocean says something very hopeful about life on this planet."

The grand tour of (and out of) the solar system continues. The primary explorers are two workmanlike spacecraft that achieved the goals scientists set before them, far surpassed their planned life spans, and adapted to new expectations by evolving technologically. Indeed, nearly 36 years after their launches — and 31 years after completing their primary missions — Voyager 1 and Voyager 2 continue to boldly go where no one has gone before.



Neptune's moon Triton, along with Earth and Saturn's moon Titan, are the only solar system objects with nitrogen-dominated atmospheres. Triton also features the coldest surface, about 38 kelvins (–391° Fahrenheit). The pinkish deposits constitute a vast south polar cap of methane ice. The dark streaks form when dust falls from geyser-like plumes, some of which Voyager 2 saw. The bluish-green band includes the so-called "cantaloupe" terrain, formed when the moon's icy crust underwent wholesale overturn. NASA/JPL

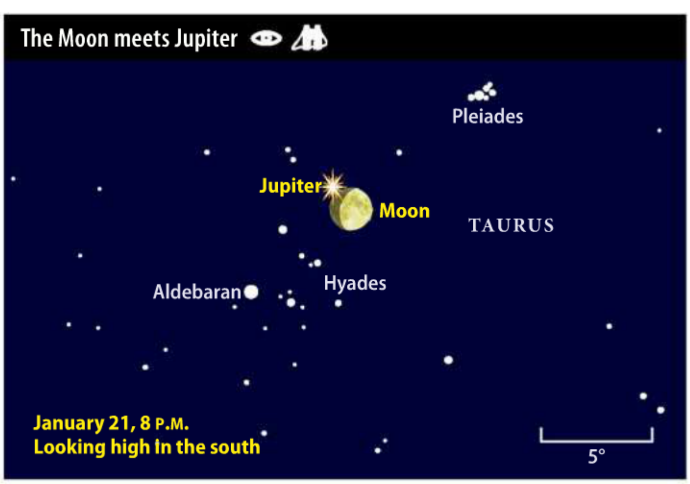
FIND MORE VOYAGER MISSION IMAGES AT **www.Astronomy.com/toc.**

MARTIN RATCLIFFE and ALISTER LING describe the solar system's changing landscape as it appears in Earth's sky.

Visible to the naked eye
Visible with binoculars
Visible with a telescope

January 2013: Jupiter's evening reign

A crescent Moon slid past Jupiter on March 25, 2012. A gibbous Moon will perform a similar maneuver in January's evening sky. JAMIE COOPER



The stars of Taurus the Bull host the Moon and Jupiter the evening of January 21, creating one of this month's prettiest celestial scenes. *ASTRONOMY*: ROEN KELLY

A new year brings hope to skywatchers that the long winter nights will prove to be clear and star-studded — and not terribly cold. When the weather cooperates, the first month of 2013 also will provide plenty of solar system targets set against the starry canopy.

Jupiter nestles nicely between the Pleiades and Hyades star clusters in Taurus the Bull, where it dominates the sky from dusk until well past midnight. The more distant giant planets, Uranus and Neptune, occupy the western sky during the evening hours. They ride above our neighbor Mars, which continues its glacial descent into the twilight glow. Early risers can look forward to exquisite views of Saturn and a brief glimpse of Venus.

We'll begin our tour of January's sky in the early evening. **Mars** lingers low in the southwest after sunset all month. Shining at magnitude 1.2, it appears inconspicuous against the twilight background. The Red Planet sets nearly two hours after the Sun on January 1, a value that drops to 90 minutes by month's end.

Two bright stars flank Mars from a healthy distance. Magnitude 0.8 Altair lies about 30° to the planet's right and nearly due west 45 minutes after sundown.

Martin Ratcliffe *provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas. Meteorologist* **Alister Ling** *works for Environment Canada in Edmonton, Alberta.*

Fomalhaut stands 35° to Mars' left and matches the planet's brightness. Use these stellar beacons to home in on our neighboring world at a slightly lower altitude. Binoculars will help you locate Mars; unfortunately, a telescope shows only a 4"-diameter disk.

If you have a sharp eye, a pristine sky, and an unobstructed horizon toward the west-southwest, you might glimpse **Mercury** on the month's final evening. The innermost planet then lies 7° to Mars' lower right and appears 2° high a half-hour after sunset. Shining at magnitude –1.2, Mercury just might pierce the bright twilight. This world reaches superior conjunction January 18, when it passes on the opposite side of the Sun from our earthly perspective. By mid-February, it will appear as high in the evening sky as it gets this year for observers at mid-northern latitudes.

Neptune stands above Mars and makes a worthy target after darkness falls. It sets four hours after the Sun in early January but dips below the horizon as twilight ends at month's end. Grab your binoculars and see if you can spot the 8th-magnitude planet among the background stars of Aquarius.

First, find Theta (θ) and Iota (ι) Aquarii, two 4th-magnitude stars that lie south of this constellation's Water Jar asterism. Next, locate 38 Aqr, a magnitude 5.4 sun roughly midway between the brighter two. Neptune is the faint speck less than 1° due east of 38 Aqr. To confirm your sighting, point a

RISING**MOON**

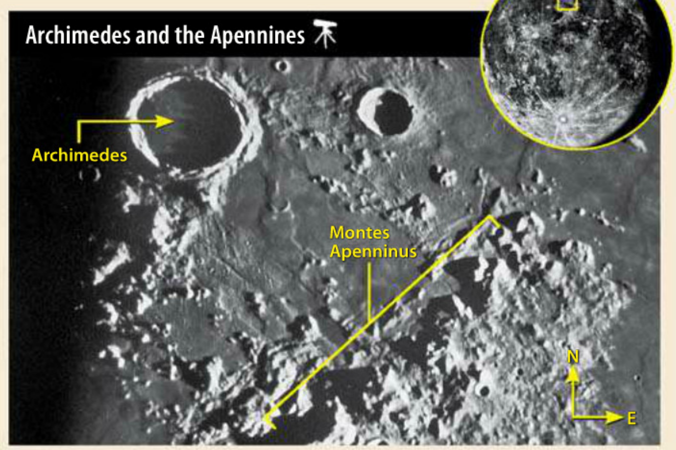
Archimedes and the jagged shadow land

Towering mountain chains and rugged crater walls span the terminator at First Quarter Moon on January 18. This parade of angular features along the day-night divide continues into the evening of the 19th. In the north, the western edge of the large, nearly circular Mare Serenitatis (the Sea of Serenity) gives way to a huge arc of mountains known as Montes Apenninus (Apennine Mountains) that forms the outer ring of the Mare Imbrium (the Sea of Rains) basin.

The massive impact that created this basin threw out an incredible amount of lunar crust. Much of this material was buried soon after when lava erupted through the cracked floor. You can see some of the excavated terrain just southeast of the Apennine chain.

Inside the mountainous arc lies the circular crater Archimedes. On the 19th, the smooth floor acts like a canvas displaying remarkable sawtooth shadows of the crater's rim. They're due to the low Sun angle, which exaggerates apparent height.

Look farther north in multi-ringed Mare Imbrium for the remains of the basin's inner wall. It shows up as a large number of both isolated and grouped peaks that sprout from the Sea of Rains. The long daggers of darkness that knife westward into the terminator shorten with each passing hour and will nearly disappear a couple of nights later.



The arc of Montes Apenninus nicely frames the 52-mile-wide crater Archimedes. This region comes into sharp relief just after First Quarter Moon. CONSOLIDATED LUNAR ATLAS/UA/LPL; INSET: LICK OBSERVATORY

telescope at the object. At medium magnification, you should see a 2.2"-diameter blue-gray disk.

Nearly 35° to Neptune's upper left lies its ice giant cousin, **Uranus**. This planet glows at magnitude 5.9 and shows up easily through binoculars. It doesn't set until late evening, which leaves lots of time for observers to track it down.

Uranus lingers in a sparse region of Pisces, near that constellation's border with Cetus. This area lies south of the Great Square of Pegasus. To find it, start at Algenib (Gamma [γ] Pegasi), the magnitude 2.8 star that marks the square's southeastern corner. Uranus lies 14° south of Algenib. Conveniently, magnitude 2.1 Alpheratz (Alpha [α] Andromedae) — the square's northeastern corner — resides the same distance north of Algenib.

Don't confuse the planet with 44 Piscium, a nearby star that shines just 0.1 magnitude

— Continued on page 42

METEORWATCH

Shooting stars brighten early January

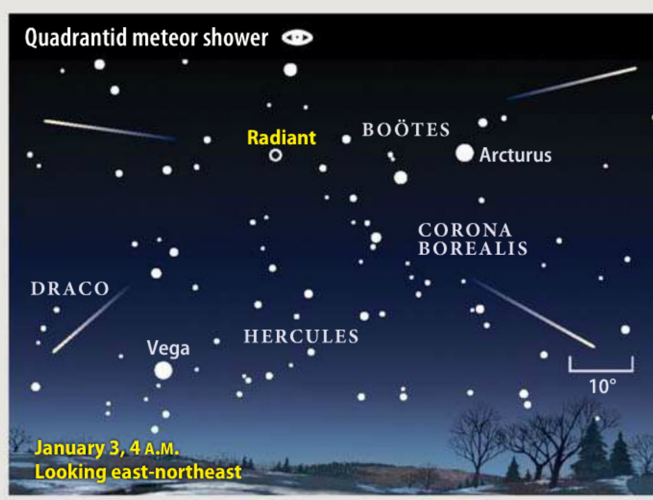
The annual Quadrantid meteor shower peaks before dawn January 3. Meteor rates rise quickly to this maximum, which should arrive at 8 A.M. EST (5 A.M. PST). This puts western North America in the prime spot. A waning gibbous Moon shares the sky with the Quadrantids, obscuring dimmer streaks. The Quadrantids generate a high percentage of bright meteors, however, so the shower should still rank among the year's best.

Under a dark sky in a typical year, the shower produces from 60 to 200 meteors per hour (with an average of about 120). Astronomers suspect that most of this variation arises from the poor weather that often occurs at this time of year and not from intrinsic variations in the shower.

The meteors appear to radiate from a spot in northern Boötes that once belonged to a constellation called Quadrans Muralis. This region climbs some 60° high in the northeast by the time morning twilight begins.

Quadrantid meteors

Active Dates: Dec. 28–Jan. 12
Peak: January 3
Moon at peak: Waning gibbous
Maximum rate at peak: 120 meteors/hour



A rush of meteors will populate the predawn sky January 3. Although the Moon will drown out fainter meteors, the Quadrantid shower should still produce a high percentage of bright ones. ASTRONOMY: ROEN KELLY

OBSERVING HIGHLIGHT The two brightest asteroids — Ceres and Vesta — remain within 15° of each other among the background stars of Taurus the Bull.

STAR DOME

How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. January 1
8 P.M. January 15
7 P.M. January 31

Planets are shown at midmonth

STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless magnified

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

JANUARY 2013

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Calendar of events

1 Asteroid Metis is at opposition, 1 P.M. EST

Earth is at perihelion (91.4 million miles from the Sun), midnight EST

3 Quadrantid meteor shower peaks

4 Last Quarter Moon occurs at 10:58 P.M. EST

5 The Moon passes 0.6° south of Spica, 3 P.M. EST

6 The Moon passes 4° south of Saturn, 8 P.M. EST

10 The Moon is at perigee (223,723 miles from Earth), 5:27 A.M. EST

The Moon passes 3° north of Venus, 7 A.M. EST

11 New Moon occurs at 2:44 P.M. EST

13 The Moon passes 6° north of Mars, 7 A.M. EST

14 The Moon passes 6° north of Neptune, noon EST

16 The Moon passes 5° north of Uranus, midnight EST

18 Mercury is in superior conjunction, 4 A.M. EST

First Quarter Moon occurs at 6:45 P.M. EST

SPECIAL OBSERVING DATE

21 A waxing gibbous Moon passes 0.5° south of Jupiter this evening.

22 The Moon is at apogee (251,848 miles from Earth), 5:52 A.M. EST

24 Mars is at perihelion (128.4 million miles from the Sun), 4 A.M. EST

26 Full Moon occurs at 11:38 P.M. EST

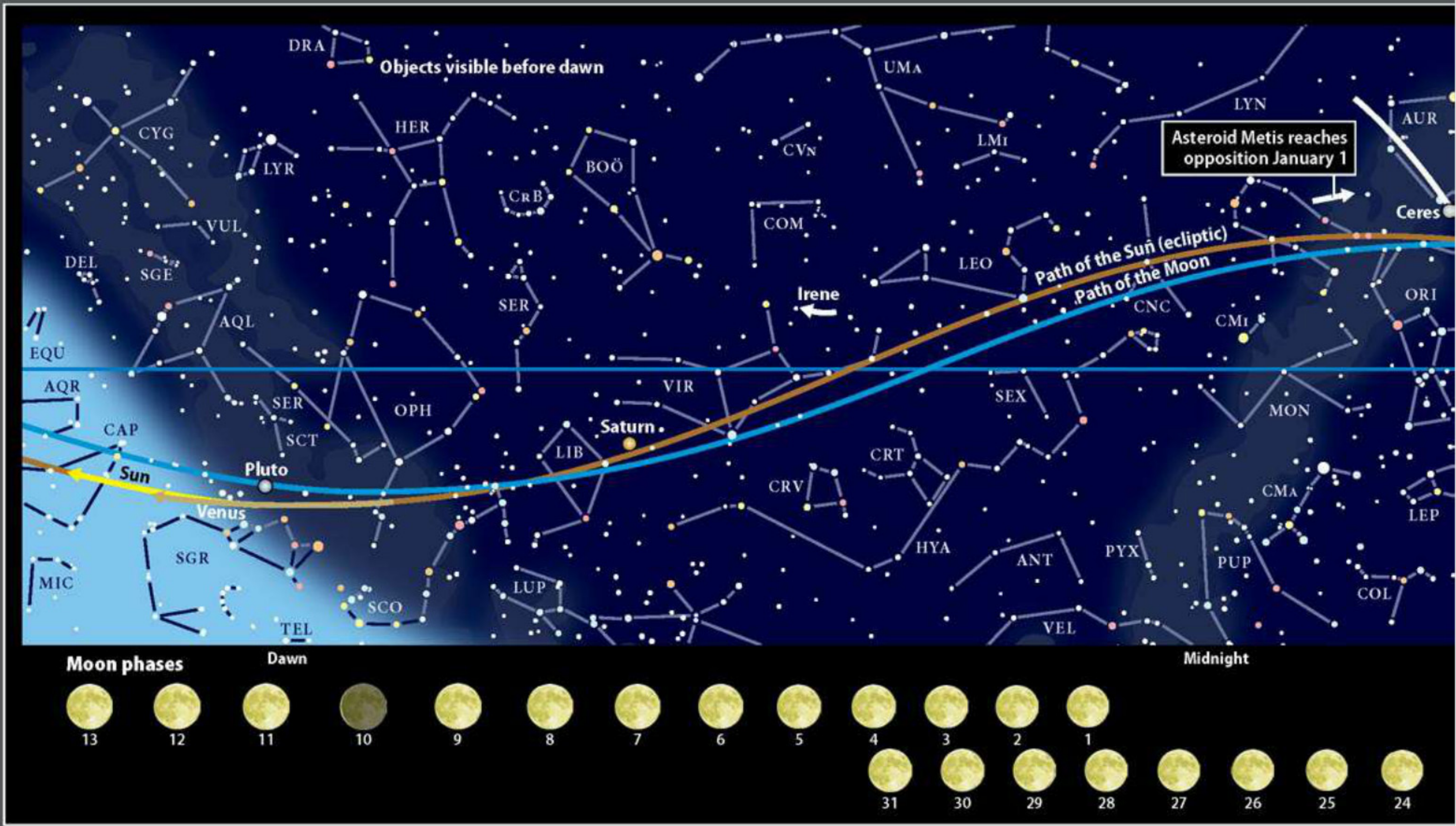
27 Asteroid Vesta is stationary, 1 P.M. EST

30 Jupiter is stationary, 11 A.M. EST

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT www.Astronomy.com/starchart.

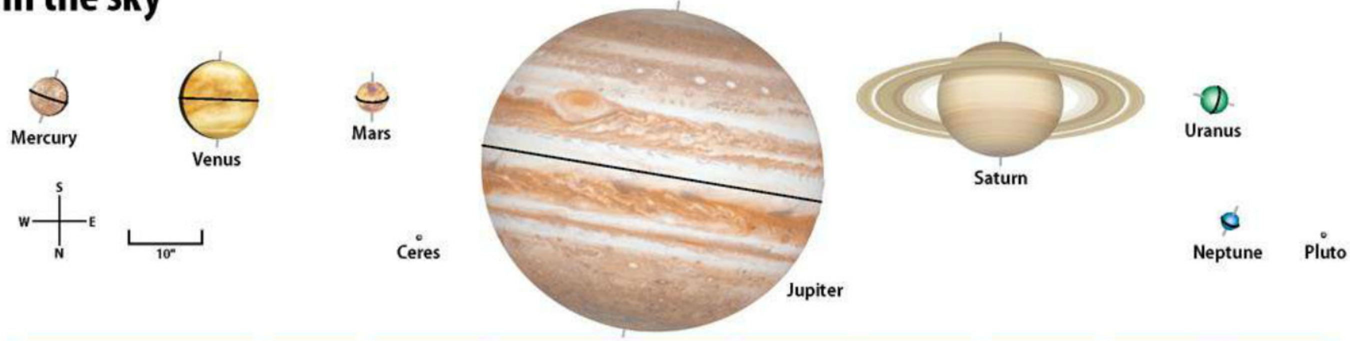
PATH OF THE PLANETS

The planets in January 2013

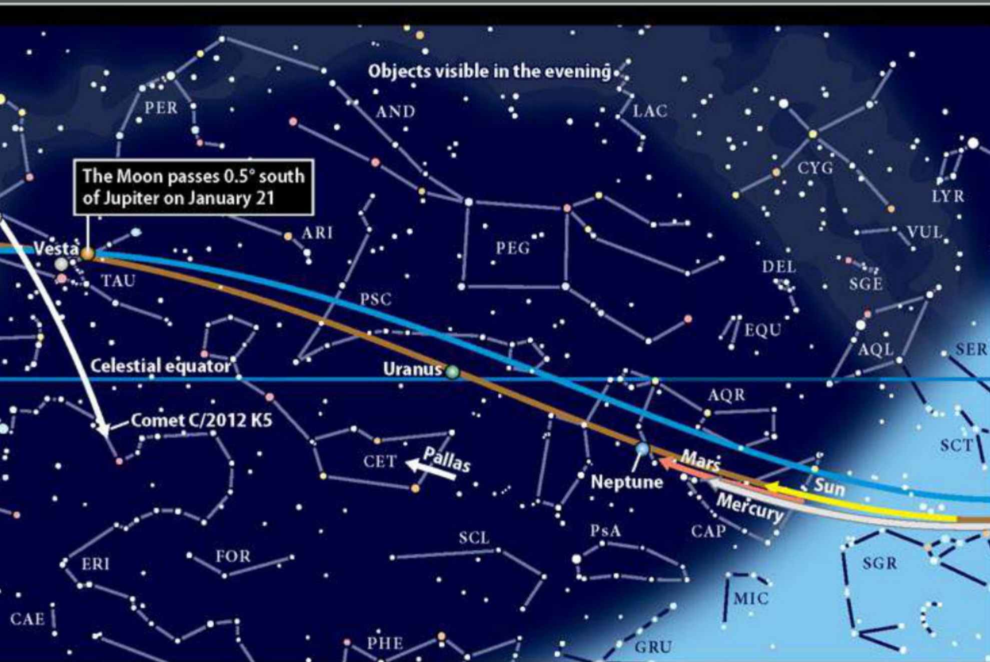


The planets in the sky

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets for the dates in the data table at bottom. South is at the top to match the view through a telescope.

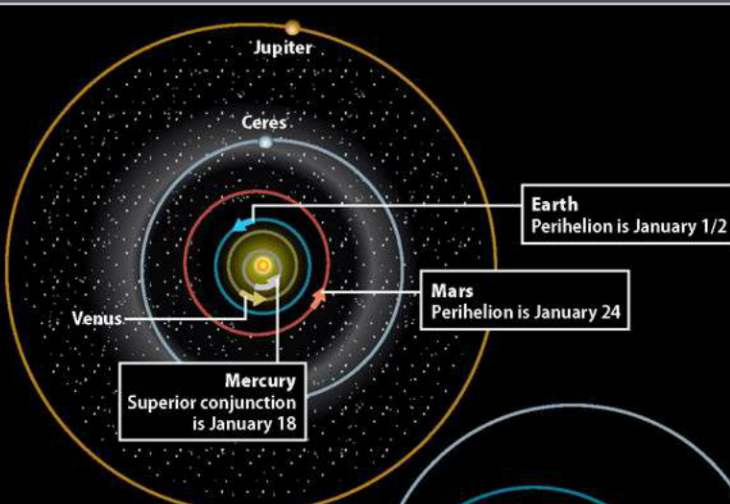


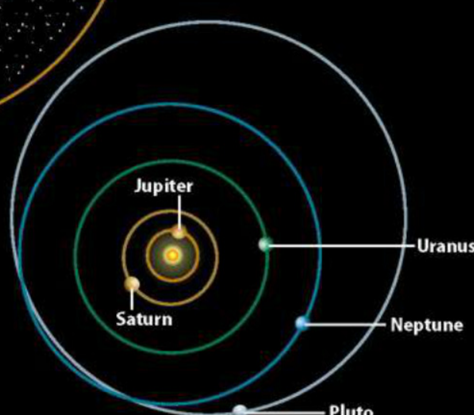
Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	Jan. 31	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15
Magnitude	–1.2	–3.9	1.2	7.5	–2.6	0.6	5.9	8.0	14.2
Angular size	5.1"	10.4"	4.1"	0.8"	45.2"	16.6"	3.5"	2.2"	0.1"
Illumination	96%	96%	98%	99%	99%	100%	100%	100%	100%
Distance (AU) from Earth	1.315	1.599	2.257	1.776	4.360	10.012	20.371	30.775	33.315
Distance (AU) from Sun	0.376	0.726	1.382	2.649	5.068	9.796	20.057	29.990	32.368
Right ascension (2000.0)	21h31.9m	18h31.0m	21h13.3m	5h19.8m	4h19.2m	14h34.7m	0h19.0m	22h14.2m	18h40.9m
Declination (2000.0)	–16°32'	–23°09'	–17°15'	26°37'	20°45'	–12°39'	1°18'	–11°35'	–19°47'



Early evening

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.
Note: Moons vary in size due to distance from Earth and are shown at 0h Universal Time.



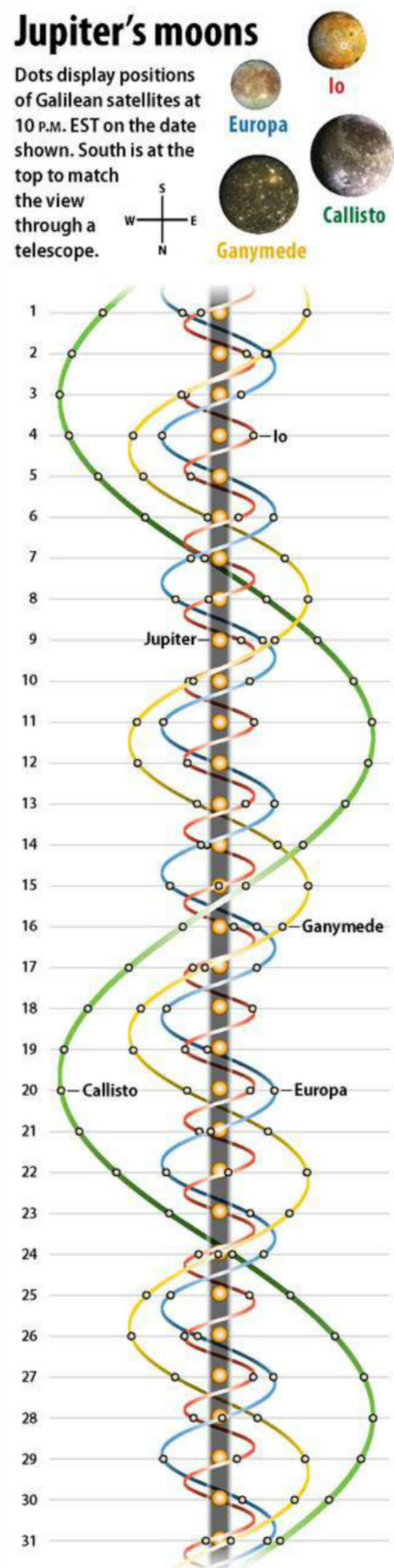


The planets in their orbits

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at mid-month from high above their orbits.

Jupiter's moons

Dots display positions of Galilean satellites at 10 P.M. EST on the date shown. South is at the top to match the view through a telescope.

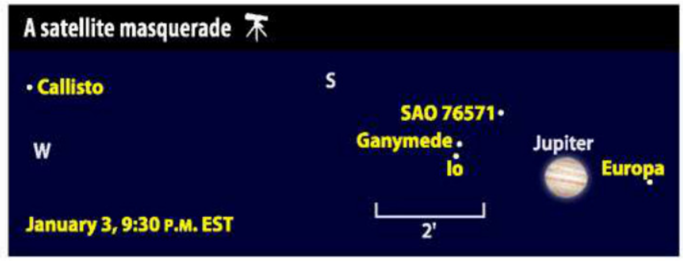


ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

— *Continued from page 37*

WHEN TO VIEW THE PLANETS

EVENING SKY	MIDNIGHT	MORNING SKY
Mercury (southwest)	Jupiter (west)	Venus (southeast)
Mars (southwest)		Saturn (south)
Jupiter (east)		
Uranus (southwest)		
Neptune (southwest)		



Jupiter appears to have five moons during January's first week when the giant planet slides past the 6th-magnitude star SAO 76571. *ASTRONOMY*: ROEN KELLY

brighter. In early January, the planet appears 2° west-southwest of the star. That gap dwindles to 1.2° by month's end. When viewed through a telescope, Uranus shows a distinctly blue-green disk that spans 3.5".

All these other worlds pale in comparison with **Jupiter**. The planet reached opposition and peak visibility in early December, and it remains the sky's "star" from dusk until the wee hours. You can spot Jupiter high in the east within 30 minutes after sunset.

Jupiter dominates a part of the winter sky already rife with bright stars. It lies in central Taurus, just 6° northwest of the Bull's luminary, 1st-magnitude Aldebaran. The stunning Pleiades star cluster (M45) stands a nearly equal distance to Jupiter's northwest. At magnitude –2.6, however, the planet shines three times brighter than the sky's brightest star, Sirius, which rises near the end of twilight.

A waxing gibbous Moon joins Jupiter the evening of January 21. At 10 P.M. EST, our satellite passes 0.5° south of the planet for a hypothetical observer at Earth's center. From North America, the two appear 0.3° farther apart but no less impressive.

Jupiter is a wonder to view through any telescope. Earthly meteorologists like to say that if you don't like the weather, just wait 10 minutes. On Jupiter, this statement is literally true. The giant sphere spins so rapidly, completing a rotation in less than 10 hours, that atmospheric features move noticeably in several minutes.

The speedy spin shows itself in two other obvious ways. First, the equator bulges outward. Jupiter's equatorial diameter is 7 percent larger than its polar diameter — 45" compared with 42" at midmonth, respectively — an effect that's easy to see through small telescopes. Second, the spin creates turbulence that often shows up dramatically along the borders between the atmosphere's dark belts and lighter zones.

Equally fascinating are Jupiter's four bright Galilean satellites. They change positions noticeably from night to night and often from hour to hour. The most exciting alignments occur when a moon and its shadow transit the planet's disk.

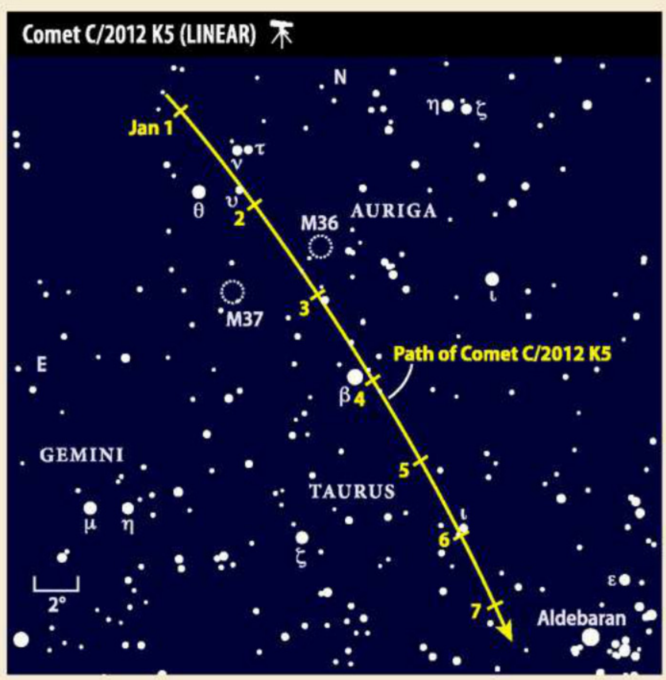
COMETSEARCH

Swimming near Auriga's splashy clusters

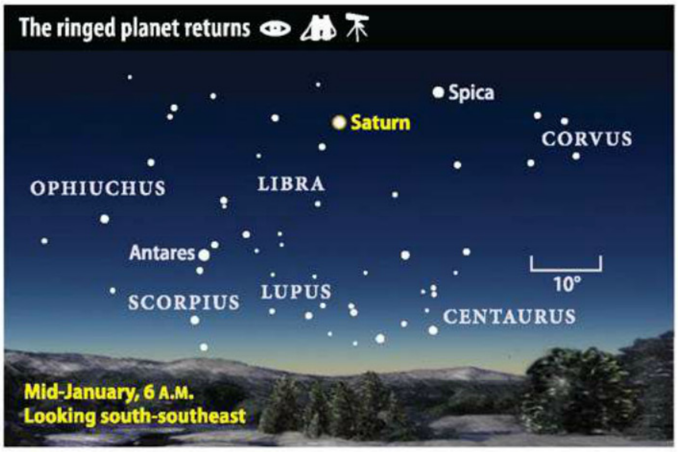
To see Comet C/2012 K5 (LINEAR) at its brightest, plan an evening trip out of town during January's first week. You'll want to search for it before the waning Moon rises, which occurs shortly after 9 P.M. local time on the 1st and roughly an hour later each night thereafter. The comet made its closest approach to Earth on December 31, 2012, when it was 27 million miles away. It dims rapidly during January from 10th to 14th magnitude.

C/2012 K5 starts the month in central Auriga, an area that lies high in the eastern sky after darkness falls. On the 2nd and 3rd, it passes between M36 and M37. These 6th-magnitude star clusters make convenient guides for experienced observers. By the 4th, the ball of ice and dust shares a low-power field with 2nd-magnitude Beta (β) Tauri and the 7th-magnitude dwarf planet Ceres (check the finder chart on page 43). If the weather cooperates, this is a great night to track down both LINEAR and Ceres.

The comet continues to dive south, passing 5° east of 1st-magnitude Aldebaran on January 7. By then, you'll need a 6- to 8-inch scope to get a reasonable view of the 11th-magnitude interplanetary traveler. At low power, you may not be able to see the diffuse dust cloud that surrounds the comet's pointlike inner coma. So, once you arrive at the right location, pump up the magnification and be sure to keep your observing eye dark adapted.



A distant Oort Cloud visitor should reach 10th magnitude in early January, when Comet C/2012 K5 sweeps south through the background stars of Auriga and Taurus. *ASTRONOMY*: ROEN KELLY



Saturn climbs higher in the morning sky with each passing week. You can find the magnitude 0.6 planet between the slightly fainter stars Spica in Virgo and Antares in Scorpius. *ASTRONOMY*: ROEN KELLY

On the evening of January 1, innermost Io and its accompanying shadow show up clearly against Jupiter's South Equatorial Belt. The moon begins its transit at 6:16 P.M. EST and takes 2 hours and 10 minutes to complete the journey. The darker, more conspicuous shadow hits the jovian cloud tops at 6:59 P.M. EST and takes one minute longer to cross the disk.

Nearly identical early evening events happen January 8, 24, and 31. Be sure to keep your telescope pointed at Jupiter, however, as the January 24 transit winds down.

Fifteen minutes before Io's shadow leaves the planet's disk at 9:25 P.M. EST, giant Ganymede begins a much rarer transit. It crosses Jupiter's south polar regions from 9:10 P.M. to 11:18 P.M. The shadow remains off in space until 1:41 A.M. (January 25), when it begins a transit that lasts until 5:55 A.M. Only West Coast observers will see this event's final stages.

Europa takes twice as long as Io to orbit Jupiter, so its transits occur half as often. The early evening of January 14 offers a good event for most North American observers. Europa first appears against the planet's disk at 5:50 P.M. EST and exits at 8:13 P.M. The shadow of the smallest Galilean moon executes a similar trajectory from 7:46 P.M. to 10:10 P.M.

For viewers who enjoy rare sights, watch Jupiter during the year's first week when the giant planet appears to gain a satellite. From January 2 to 5, the 6th-magnitude double star SAO 76571 lies within 10' of the giant planet. The double passes closest to Jupiter on the 3rd, when it appears nearer than any Galilean moon. Crank up the power to split the double into its components. You'll see a nice color contrast between the slightly brighter red giant primary and the blue-white secondary.

Saturn rises shortly before 3 A.M. local time January 1 and some 30 minutes earlier with each passing week. The best views come roughly an hour before dawn, when the planet stands more than 30° high in the south. Saturn lies in Libra, a constellation devoid of bright stars. Shining at magnitude 0.6, it easily outshines its neighbors.

Early mornings are typically cold in January, but nothing stirs the soul better on a frigid night than a view of Saturn through a telescope. The planet's disk appears 17" across at midmonth while its rings span 38" and tilt 19° to our line of sight.

Brilliant **Venus** rises shortly after twilight begins in early January. Its elongation from the Sun gradually declines during the month, however, and it becomes hard to see low in the southeast by the 31st. The planet glows at magnitude –3.9, bright enough to shine through the twilight. A quick peek through a telescope reveals an almost full disk with an apparent diameter of 10".

Look for a slender crescent Moon rising with Venus the morning of January 10. Our satellite, less than 35 hours before its new phase, will be hard to see 3° to Venus' left.

LOCATING**ASTEROIDS**

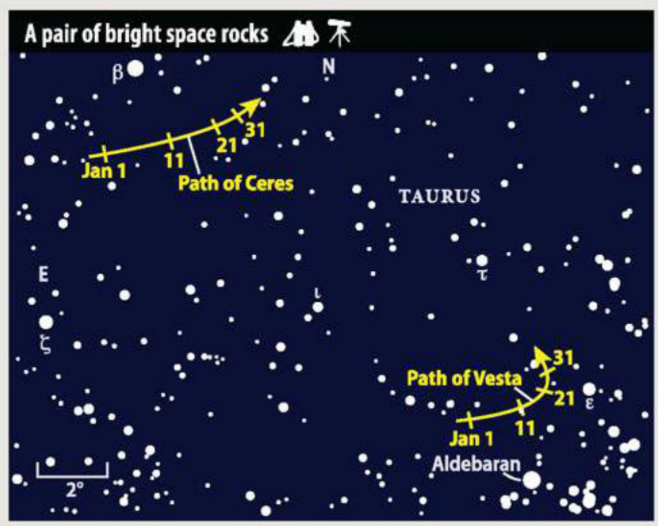
The Bull hosts two main-belt objects

How's this for easy? Walk outside, point your binoculars at a bright star, and spot an asteroid in the same field of view. To make things even better, you can perform this task in January with the two brightest asteroids: 1 Ceres and 4 Vesta.

Second-magnitude Beta (β) Tauri is the blue-white star that marks the tip of Taurus the Bull's northern horn. Just to its south are huge clouds of obscuring dust and cold gas that line the Milky Way. These clouds look impressive through binoculars and wide-field scopes under a dark sky because they lack lots of stars.

The biggest asteroid lies in this sparse region. Ceres glows at magnitude 7.1 to start the month and fades slowly as it tracks along the channel of darkness during the next few weeks. To see the asteroid's motion against the stellar background, you'll need to revisit the area every three or four nights.

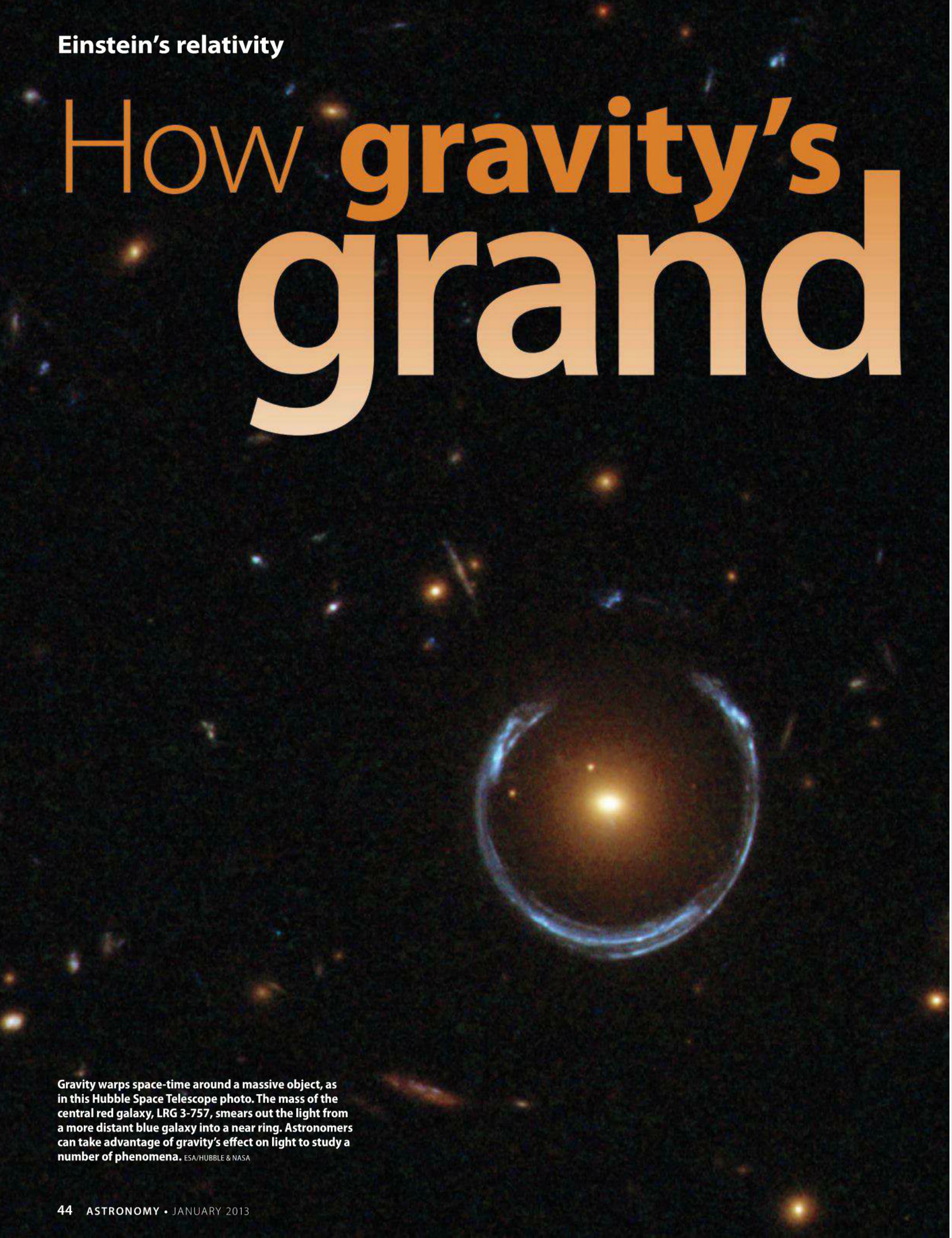
Vesta has an even brighter guide star. First-magnitude Aldebaran is the starting point for this asteroid, which glows slightly brighter than Ceres. Vesta spends January no more than 3° north of Taurus' luminary. The background here — formed largely by the Hyades star cluster — is much richer than by Ceres, but the finder chart below should let you pick it out from the distant suns.



Asteroids Ceres and Vesta lurk in Taurus the Bull this month, a short distance from each other and from bright stars. *ASTRONOMY*: ROEN KELLY

Einstein's relativity

How gravity's grand



Gravity warps space-time around a massive object, as in this Hubble Space Telescope photo. The mass of the central red galaxy, LRG 3-757, smears out the light from a more distant blue galaxy into a near ring. Astronomers can take advantage of gravity's effect on light to study a number of phenomena. ESA/HUBBLE & NASA

This cosmic force that warps space provides a lens to study distant galaxies, exoplanets, dark matter, and more. **by Ray Villard**

illusion reveals the universe

On a clear, dark night, the starry sky looks deceptively placid to casual observers and astrophysicists alike. Gaze deeply into the universe with a powerful telescope, however, and it looks like a funhouse mirror.

Rich clusters of galaxies reveal spider webs of light. Glowing arcs wrap the clusters in concentric patterns. At first glance, it looks like someone used window cleaner on the telescope's mirror and left behind swirl-shaped streaks.

These arcs are nature's grandest illusion, caused by gravity bending, magnifying, and amplifying light that originates in the far corners of the universe. The effect is called gravitational lensing, and it's analogous to a magnifying glass that expands and distorts — and can even make multiple copies of — an object's image.

The extremely sharp and sensitive observations from NASA's Hubble Space Telescope have uncovered a multitude of gravitational lenses across the cosmos. At least a million examples probably lie scattered throughout the sky.

A century ago, the idea of matter warping space like a twisted rubber sheet lay only in the imagination of Albert Einstein. When astronomical observations did discover gravitational lensing, it was little more than a novelty. But today, it routinely serves as an extraordinarily useful probe of otherwise unseeable objects and phenomena in the universe.

Gravitational lensing allows astronomers to map the distribution of otherwise invisible dark matter in space. It's also a powerful telephoto lens that lets scientists zoom in on extremely distant objects, and it can uncover extrasolar planets too far and dim for any other observational method to detect. Not bad for an unusual quirk of space-time.

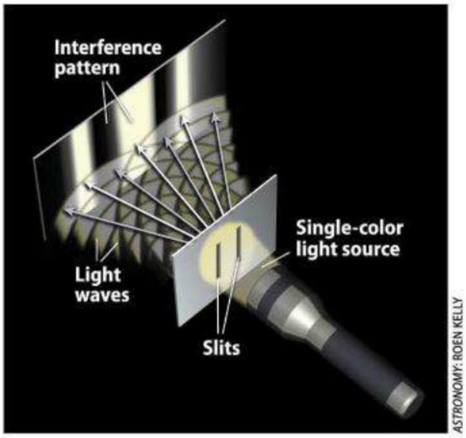
Ray Villard *is news director for the Space Telescope Science Institute in Baltimore, which oversees Hubble's operations.*

Understanding light

Sir Isaac Newton's laws of gravity first predicted that light could be susceptible to the pull of gravity. In his 1704 treatise, *Opticks*, he described light as a stream of infinitesimally small particles called corpuscles. Newton assumed that these particles had mass and therefore could be deflected along their trajectory.

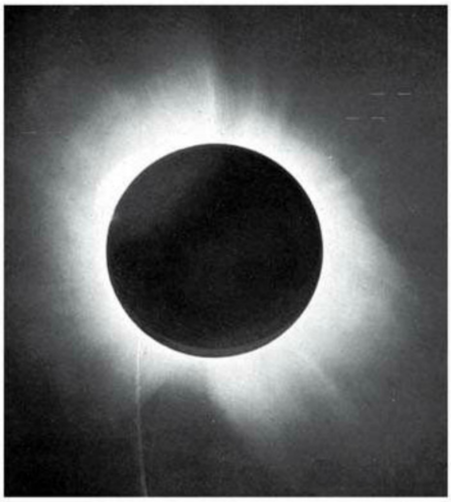
In the early 1800s, English scientist Thomas Young performed an experiment that showed light must be made up of waves of energy. He discovered that passing light through a barrier with two slits produced interference patterns of bright and dark bands on a screen. Light particles could not do this. He concluded that light must be massless and therefore beyond gravity's reach.

The birth of quantum physics theory in the early 1900s settled the question by describing both matter and energy (including light) as having particle-like *and* wave-like behavior. At the same time, Einstein's

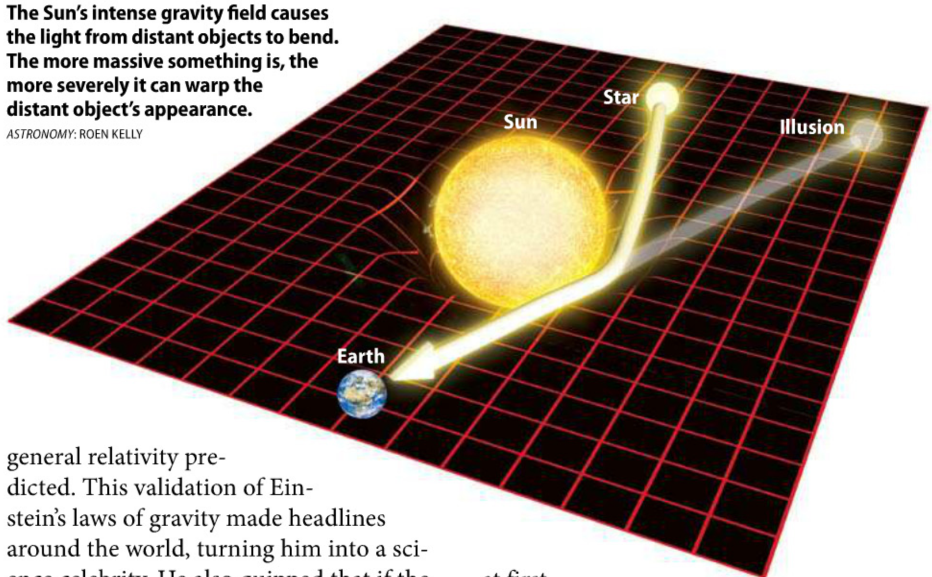


The famous double-slit experiment helped convince 19th-century scientists that light behaves as a wave. As the light exits the two slits, it produces an interference pattern on the background screen, which wouldn't be the case if light were solely made of particles.

A century ago, the idea of **matter warping space like a twisted rubber sheet** lay only in the imagination of **Albert Einstein**.



The total solar eclipse of 1919 provided the first evidence to support Albert Einstein's general theory of relativity — including the prediction that the Sun's mass could bend the light of faraway stars. F. W. DYSON/A. S. EDDINGTON/C. DAVIDSON



The Sun's intense gravity field causes the light from distant objects to bend. The more massive something is, the more severely it can warp the distant object's appearance. *ASTRONOMY*: ROEN KELLY

general theory of relativity described gravity as a warping of space-time, rather than the instantaneous force reaching across space that Newton had imagined. Therefore, gravity can change the trajectory of photons — particles of light — even though they don't have mass.

Measuring the moved light

Remarkably, the idea that gravity can influence light is testable. The closest massive object is the Sun, but it's only possible to see how it affects the incoming light from distant stars during a total solar eclipse (when the Sun dims enough to render them visible).

In 1919, British astronomer Arthur Eddington led an expedition to the island of Principe near Africa's west coast to observe the total solar eclipse. He found that the path from the faraway stars' light did indeed bend, and by the same amount general relativity predicted. This validation of Einstein's laws of gravity made headlines around the world, turning him into a science celebrity. He also quipped that if the observations failed, "Then I would feel sorry for the dear Lord. The theory is correct anyway."

Einstein, along with Russian physicist Orest Khvolson a decade before him, would go on to formally describe how gravity could magnify the image of a background object, warp the image into rings or arcs, and even produce multiple copies. It all depends on the spatial alignment between the background object and foreground gravitational lens.

They also both calculated that lensing effects would be too small to ever be observable through telescopes. Einstein condescendingly wrote that he published the analysis simply to satisfy the curiosity of an amateur astronomer who pressed him on the question. The great physicist overlooked the fact that a galaxy or cluster of galaxies locks up a tremendous amount of mass, enough to create a much bigger lens.

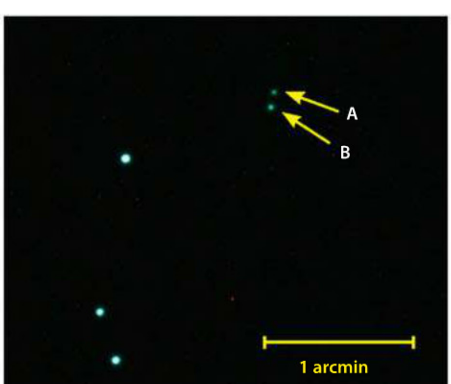
It wasn't until 1979 that observations of the so-called "Twin Quasar" SBS 0957+561 confirmed the first gravitational lens. What at first appeared to be two separate quasars turned out to be images of the same object. The biggest clue was that any change in one of the quasar's brightness would always appear about 14 months later in the other. Due to the warping of space, light from the latent quasar image had to travel more than 1 light-year farther than light from the "companion" quasar, delaying its arrival at Earth. The quasar lies 8.7 billion light-years away while the foreground lensing galaxy lies only 3.7 billion light-years distant.

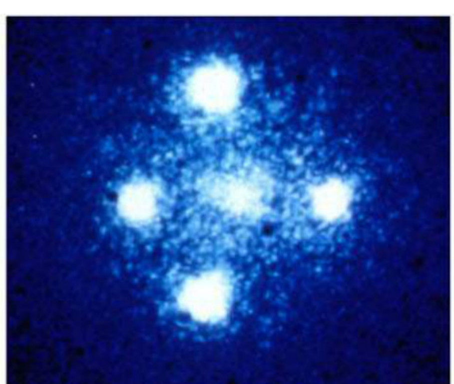
Lens types

Today's telescopes can detect various strengths of lensing phenomena. For example, a "strong gravitational lens" results in arcs so geometric that they were initially dismissed as photographic artifacts. This type of lens can magnify a single distant galaxy to the point where details of its structure appear. A strong lens also can enlarge extremely distant galaxies that are too far away to be visible otherwise.

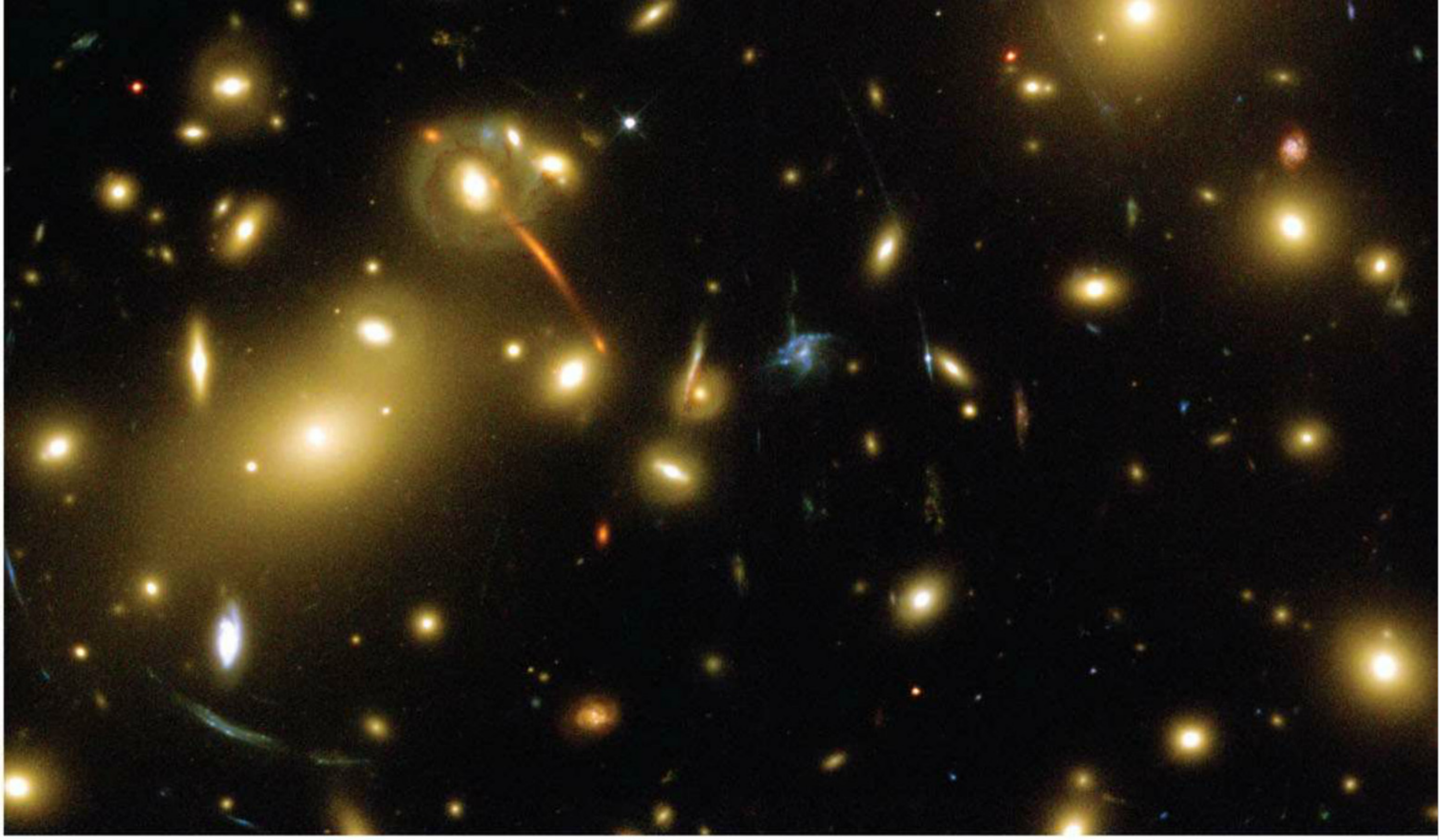
When the gravitational lens is not strong enough to form multiple images or arcs, it can still make subtle distortions in background objects called weak gravitational lensing. Just as the images of pebbles at the bottom of a pool appear distorted due to light's refraction through water, the light from distant galaxies passes through the gravitational influence of intervening clusters, resulting in warped or stretched images.

Weak gravitational lensing accounts for most of the lensing effects in the universe. In this case, the background galaxies can still appear distorted through stretching (an effect called shear) and magnification. Statistics from the distribution of the





The "Twin Quasar" SBS 0957+561 (left), which is in fact two images of the same object, provided the first example of a gravitational lens in space in 1979. At right, G2237+305 (also known as the Einstein Cross) provides an even more dramatic example of a gravitational lens: A single distant quasar appears four times around the central, closer object. MATTHIAS LANGER/AYLIN ESEN AND ÖNDER HOSGÖR (AIR-WKDO); NASA/ESA/STScI



Galaxy cluster Abell 2218 is massive enough to smear and stretch the light from distant galaxies, resulting in an unparalleled view of gravitational lensing. NASA/ESA/RICHARD ELLIS (CALIFORNIA INSTITUTE OF TECHNOLOGY)/JEAN-PAUL KNEIB (OBSERVATOIRE MIDI-PYRENEES)/A. FRUCHTER/ERO TEAM (STScI AND ST-ECF)

background sources help determine the shape and mass of the foreground galaxy cluster doing the lensing.

When the Hubble Space Telescope launched in 1990, its high resolution capacity — 10 times sharper than ground-based scopes of the time — allowed it to see lensing in every galaxy cluster it peered at. One seminal picture showed galaxy cluster Abell 2218, which lies about 2 billion light-years away in Draco the Dragon. Astronomers had never before seen so much gravitational lensing. Ground-based telescopes could pick up the biggest and brightest arcs, but Hubble revealed 10 times as many.

Even where no distortion in shape is apparent, so-called "microlensing" is visible as a brief amplification of the amount of light from a background object. Unlike other forms of lensing, however, microlensing is a temporary event because it occurs when a foreground object drifts in front of a background star. Such occurrences produce distinctive bell-shaped light curves, unmistakable signatures of a lensing event rather than a stellar flare or nova. This results in a powerful technique for searching out extrasolar planets throughout the galaxy beyond the reach of other planet detection methods.

The **light from distant galaxies** passes through the **gravitational influence of intervening clusters**, resulting in **warped or stretched images**.

The exoplanet known as OGLE-2005-BLG-390Lb, seen in this artist's conception, is one of many worlds astronomers have discovered thanks to gravitational microlensing. NASA/ESA/G. BACON (STScI)

Substellar searches

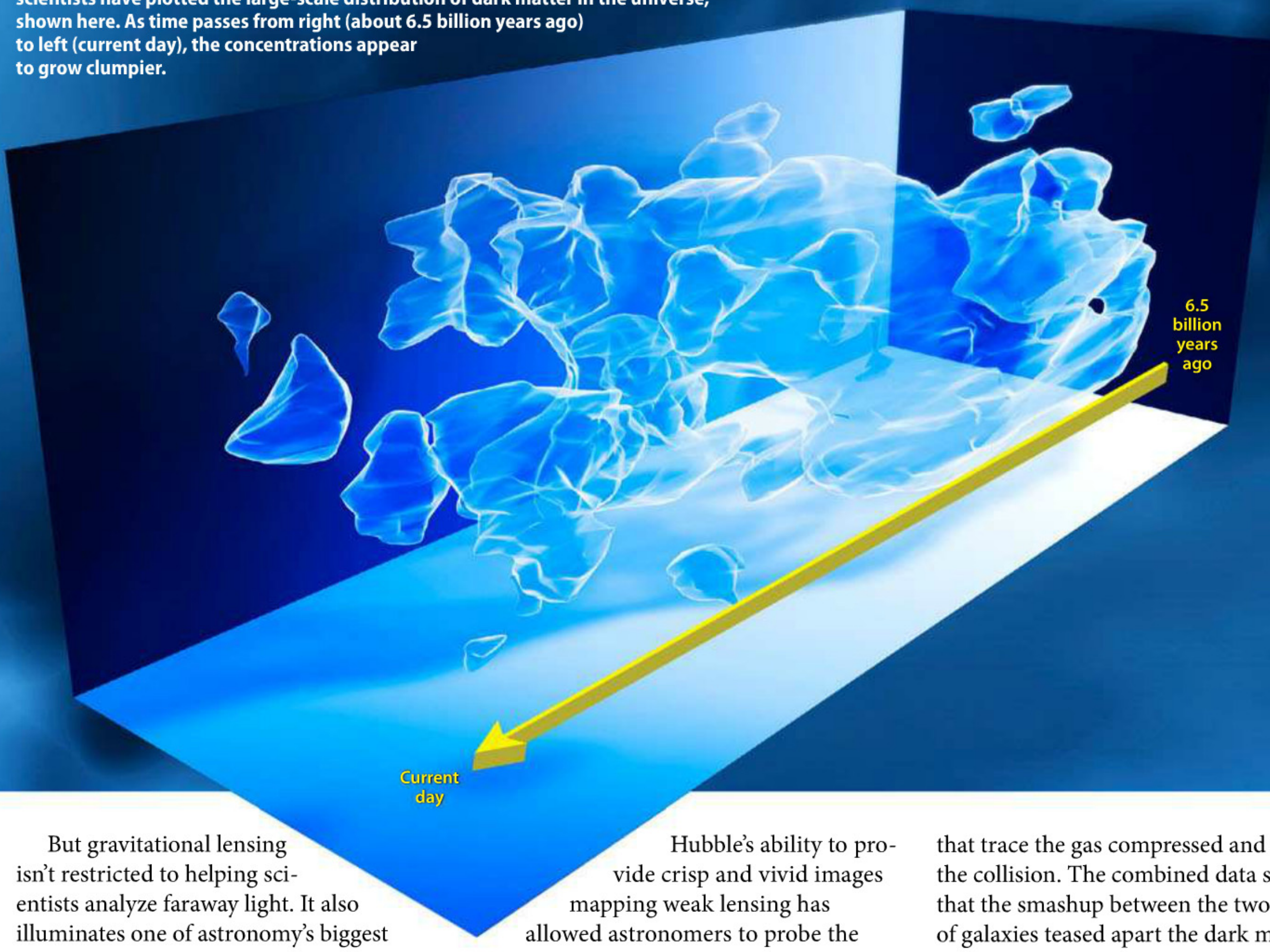
For the past 20 years, groups of astronomers such as the Optical Gravitational Lensing Experiment and Microlensing Observations in Astrophysics have used telescopic "surveillance cameras" to stare at tens of millions of stars in the direction of the Milky Way's galactic center. They are looking for transient events that result when a foreground object magnifies the light from a background star.

This technique works not only for stars but also for smaller objects in the foreground, too, down even to the edge of a free-floating black hole — assuming they're out there. A planetary companion around the foreground object can produce additional brightening of the background star.

The higher the mass of the lensing star, the longer the duration of the microlensing event. Typical events of this type last about a month as the star drifts past the background object. But the extra brightening due to a planet typically lasts a few hours to a couple of days. Using the microlensing technique, astronomers can determine that planet's mass, too. Recent studies have found that, statistically, our galaxy contains a minimum of 100 billion planets.

Dark matter's distribution

Dark matter, whatever it may turn out to be, makes up about 84 percent of all mass and keeps galaxies from flying apart. By taking advantage of gravitational lensing, scientists have plotted the large-scale distribution of dark matter in the universe, shown here. As time passes from right (about 6.5 billion years ago) to left (current day), the concentrations appear to grow clumpier.



NASA/ESA/R. MASSEY (CALIFORNIA INSTITUTE OF TECHNOLOGY)

But gravitational lensing isn't restricted to helping scientists analyze faraway light. It also illuminates one of astronomy's biggest mysteries: dark matter.

Seeing the invisible

In 1933, Zwicky came across a problem when studying the motions of distant galaxies. He estimated the total mass of a group of galaxies by measuring the collective brightness of its stars. When he determined the galaxies' velocities, however, they were moving way too fast to stay glued together through gravity. The collection should have flown apart long ago. To hold it together, he reasoned, the galaxies needed 400 times more mass than was locked up in their stars.

Astronomers began to realize that only large amounts of hidden mass could explain the dilemma. Galaxies and galaxy clusters must be embedded on an invisible scaffolding of unseen material, quickly dubbed "dark matter." Today, we know that dark matter makes up some 84 percent of the mass in the universe.

Hubble's ability to provide crisp and vivid images mapping weak lensing has allowed astronomers to probe the distribution of dark matter in galaxy clusters. By precisely measuring the "bending power" of the lens, astronomers can determine the mass of the cluster in a way that is entirely independent of how much light it emits. Zwicky first speculated about making such a measurement decades before it actually happened.

Hubble astronomers recently used weak lensing to reconstruct a large-scale, three-dimensional map of the distribution of dark matter in the universe. The map stretches halfway back to the Big Bang and reveals a loose network of the dark-matter filaments that bind galaxies.

In a groundbreaking photo, astronomers combined the power of Hubble with NASA's Chandra X-ray Observatory to trace dark matter's distribution in the titanic collision of two galaxy clusters known as the Bullet Cluster. Hubble microlensing data generated the dark matter maps while Chandra detected the X-rays that trace the gas compressed and heated by the collision. The combined data sets show that the smashup between the two clusters of galaxies teased apart the dark matter and normal matter.

Zooming into space

The deepest optical and infrared views of the universe reveal how galaxies evolved from about 13 billion years ago to today. This is embodied in the Hubble Ultra Deep Field, a photo compiled from multiple visible — and infrared — light observations of a small region of sky made from 2004 to 2012 that shows about 10,000 galaxies.

The most distant represent a time when the universe was only a few hundred million years old, their light only now arriving at Earth's observatories. The challenge is that the signal not only is faint, but also appears small in the sky.

Astronomers would like to see how star formation progressed within these galaxies billions of years ago. Such details would be beyond the reach of Hubble's vision were it not for the magnification made possible by gravitational lensing.

DISCOVER AN EASY WAY TO EXPERIENCE THE EFFECTS OF GRAVITATIONAL LENSING FROM HOME AT **www.Astronomy.com/toc.**

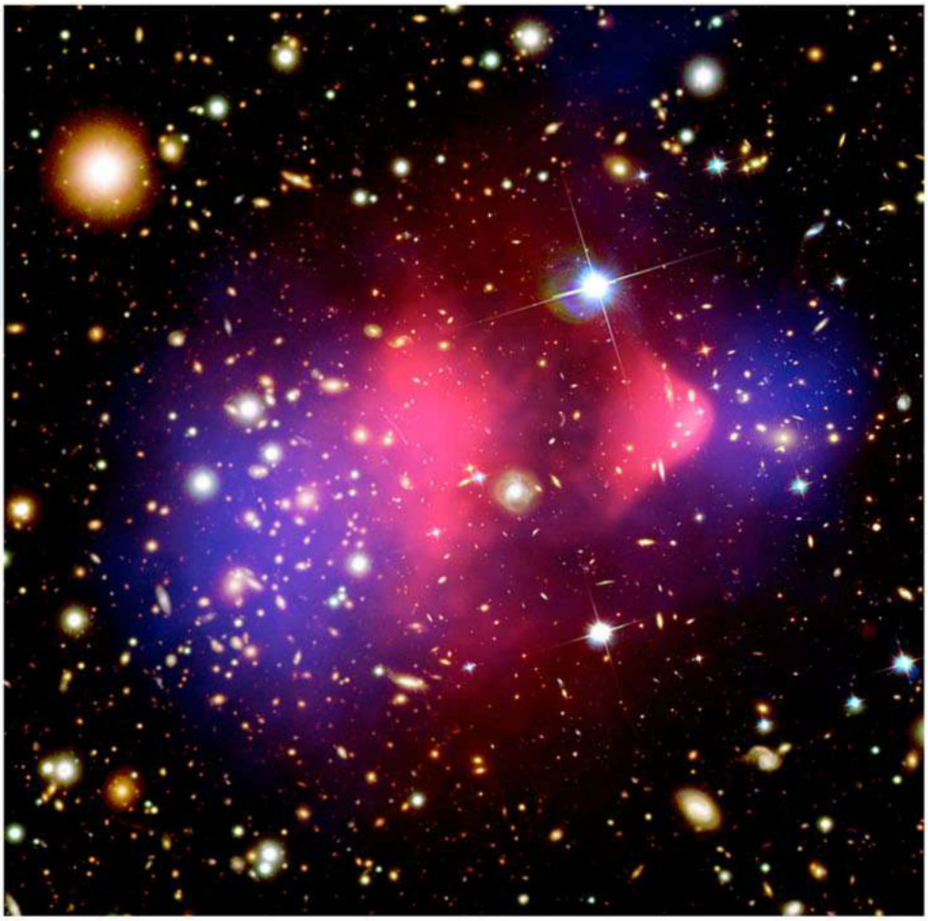
Astronomers traced **dark matter's distribution** in the **titanic collision of two galaxy clusters** known as the Bullet Cluster.

This offers the opportunity to leapfrog even further into the past than initially achievable in select observations that would otherwise require the use of a much larger space telescope. With the increased magnification from the gravitational lens, Hubble can resolve knots of the brightest and most massive star clusters in a remote galaxy.

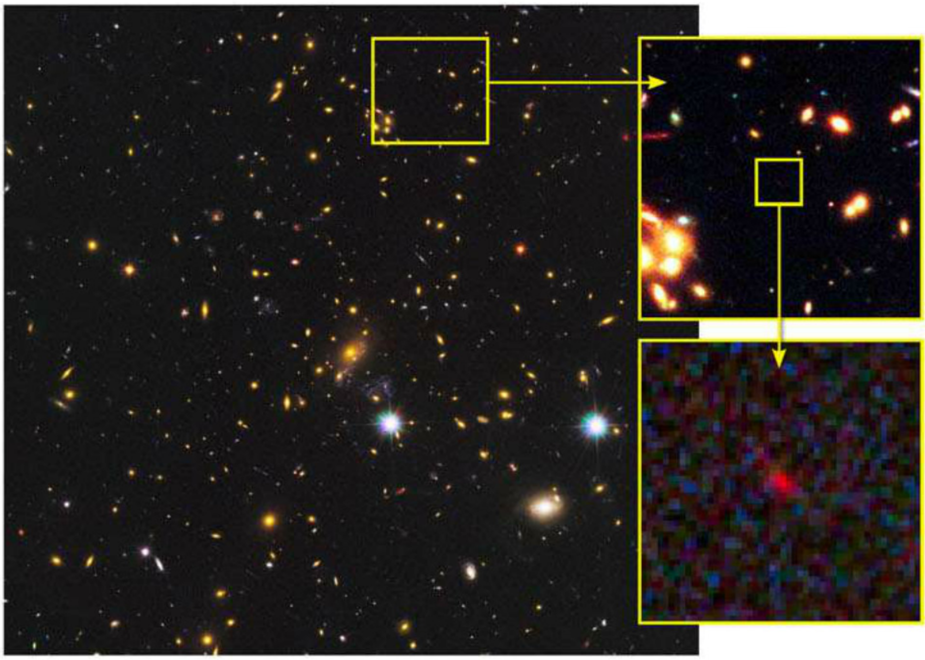
An ambitious effort that goes fishing for the farthest observable galaxies is the Cluster Lensing And Supernova survey with the Hubble program, presently using hundreds of Hubble orbits over the next few years. This technique has uncovered one of the farthest protogalaxies ever seen, which existed 13.2 billion years ago. The foreground lensing cluster, MACS J1149+2223, is much younger. Without lensing to boost the distant object's brightness to 15 times greater than normal, it would have been too faint for Hubble. The protogalaxy is so small (about 1 percent of the Milky Way's mass) that it may be in the first steps of forming an entire galaxy, or it could be a small part of an even larger galaxy.

This likely will remain one of the most distant gravitationally lensed remote galaxies until Hubble's successor, the James Webb Space Telescope, launches later this decade. Because Webb will be sensitive to infrared wavelengths, it will observe such galaxies at even greater distances, which are invisible at Hubble's wavelengths.

Over the past century, gravitational lensing has gone from an obscure theory to an indispensable tool for unraveling some of the universe's deepest secrets. It is exactly the kind of quirky outcome of the universe's underpinnings that British geneticist and evolutionary biologist J. B. S. Haldane imagined decades ago when he said, "Now my own suspicion is that the universe is not only queerer than we suppose, but queerer than we *can* suppose."



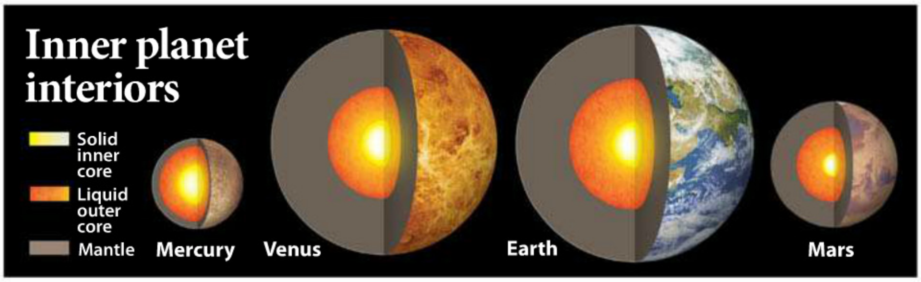
The Bullet Cluster, also known as 1E 0657-556, is the result of a tremendous collision between two galaxy clusters. In this composite photo, pink represents hot gas and blue represents dark matter (as determined by studying the cluster's gravitational lensing). X-RAY: NASA/CXC/M. MARKEVITCH, ET AL.; OPTICAL: NASA/STScI/MAGELLAN/U. ARIZONA/D. CLOWE, ET AL.; LENSING MAP: NASA/STSCI/ESO WFI/MAGELLAN/U. ARIZONA/D. CLOWE, ET AL.



One of the farthest protogalaxies astronomers know of, from just 500 million years after the universe began, was found via gravitational lensing. NASA/ESA/W. ZHENG (JHU)/M. POSTMAN (STScI)/THE CLASH TEAM

LEARN MORE Gravitational lensing helps scientists learn about a number of phenomena that *Astronomy* has covered in depth. To purchase a PDF package of some of these articles, visit **www.Astronomy.com/extracontent**.

WEIGHTY WORLD



The solar system's four terrestrial planets each holds a metallic interior, but Mercury is the oddball — its core spans more than 80 percent of the innermost world's width. ASTRONOMY: ROEN KELLY, AFTER NASA

Q: WHY DOES MERCURY HAVE SUCH A LARGE CORE?

Philip Lynch, *Tony, Wisconsin*

A: One of the enduring enigmas of Mercury is why such a small planet, roughly 38 percent of Earth's diameter, is so dense. From Mariner 10's 1974–5 flybys of the innermost world and now the orbiting MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft, we know Mercury has an average density of 5.43 grams per cubic centimeter. (Earth's average density is 5.52 g/cm^3.) This value means the planet must hold a high percentage of iron because the rocky surface material is much less dense than the planet's average. New results from MESSENGER indicate that the metallic core likely makes up more than 80 percent of Mercury's diameter.

No other inner solar system planet has a core that constitutes so much of its interior. So how did Mercury end up this way? One possibility is that in the early solar nebula, gas drag affected the bodies that were richer in rocky silicate materials more than metal-rich bodies, essentially sorting them and leading to less rocky material closer to the Sun. Alternatively, some scientists have proposed that during an early, active phase of the Sun, much of Mercury's rocky exterior evaporated away. This would have led to a lower percentage of more-volatile elements that radioactive decay produces, such as uranium and potassium, at the surface relative to elements that are harder to vaporize, such as thorium. However, MESSENGER's gamma-ray spectrometer has found no such depletion, ruling out this hypothesis.

Another possibility is that Mercury may have experienced a giant impact early in its history, similar to the one that many scientists think formed the Moon. Such an impact could have ejected much of the rocky exterior, leaving behind a metal-rich planet. While there is no simple answer yet, we are making important progress thanks to MESSENGER.

Steven A. Hauck, II
Case Western Reserve University, Cleveland

Q: WHAT IS THE AVERAGE TIME FOR DUST DISCHARGED FROM A SUPERNOVA TO BE RECONSOLIDATED IN PART OR WHOLE TO FORM A NEW STAR?

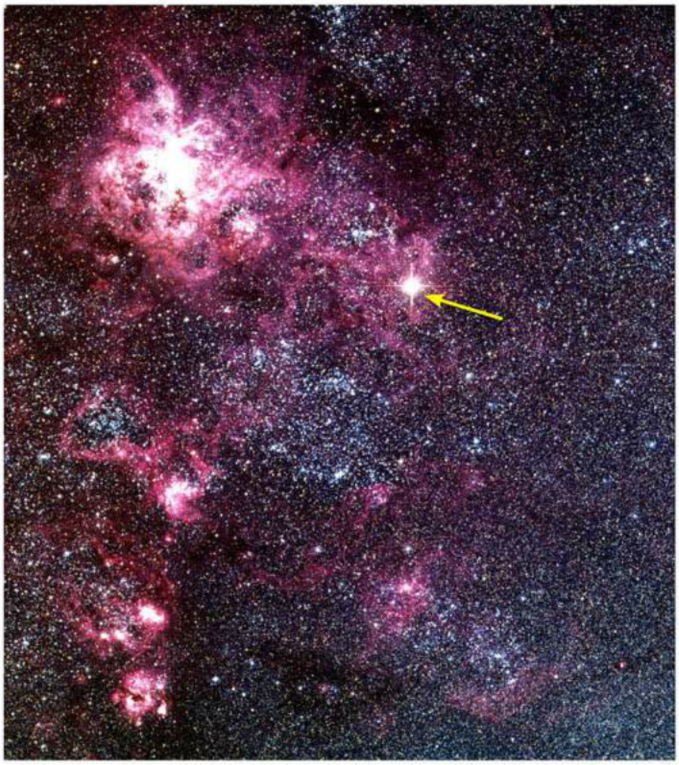
Gary Jewell
Creston, California

A: A dust grain ejected when a massive star explodes as a supernova can follow a few different paths. One possibility is that it will leave its host galaxy entirely as part of a galactic wind. Nearly half of all grains in the Milky Way today may suffer this fate. Some of these grains will be destroyed in our galaxy's hot halo and some will eventually fall back, but either way the process will take at least 10 billion years.

The dust grains that don't leave the galaxy, or that leave and return, will find themselves drifting through the interstellar medium (ISM) — the low-density gas that occupies the space between the stars. Most of these grains, too, will never make it into another star.

If a supernova's shock waves hit a grain, the dust suddenly experiences a headwind of interstellar hydrogen atoms striking it at hundreds of kilometers per second. These atoms knock pieces off the grain in a process known as sputtering. Eventually, this breaks down the dust into its constituent atoms. In our galaxy, the average grain encounters a supernova shock strong enough to destroy it within a few hundred million years of its formation.

Sputtering destroys the grain, but the constituent atoms survive. They may create new dust grains that condense in the ISM, or they may remain as free atoms. In either case, given



Some of the dust released when Supernova 1987A (arrow) exploded will break down into atoms within a few hundred million years if the Large Magellanic Cloud's galactic wind doesn't kick it out of that galaxy. Those atoms will be recycled into a new star a few billion years later. ESO

enough time, the grain's atoms eventually will find themselves in an unstable region of the ISM that is collapsing to make a new star. The average time required for this to happen in the Milky Way is a few billion years.

Mark Krumholz
University of California, Santa Cruz

Q: I'VE HEARD THAT MOST OF EARTH'S WATER CAME FROM COMETS, BUT WHERE DID ALL THE WATER IN THOSE COMETS COME FROM?

Thomas Kumiega Sr.
Moosup, Connecticut

A: Actually, comets may not be the most important source of Earth's water. Computer simulations show that the scattering of comets inward from the realm of the giant planets was inefficient, and Jupiter and Saturn scattered most of these icy bodies out of the solar system. Also, the fraction of heavy hydrogen (called deuterium) in water in at least some comets differs from what scientists measure in Earth's oceans (although Comet 103P/Hartley provides a good match).

An alternative possibility is that Jupiter scattered primitive bodies in the region now called the asteroid belt, and those objects collided with Earth. Rather than very small bodies, as is currently the case, the objects in this region may have been the size of the Moon or Mars — but with the composition of today's asteroids. Because these bodies were already closer to the Sun than Jupiter, the giant planet could have scattered them efficiently toward Earth.

We know that meteorites contain the same fraction of deuterium, on average, as Earth's water does. A variant on this idea has Jupiter plowing into the primordial asteroid belt, dragging both icy bodies and asteroid material inward, so Earth's water may have come from comets and asteroids.

The origin of water itself lies in the stability of the water molecule: It forms readily in interstellar clouds and is likely the most abundant solid-forming material in planetary systems.

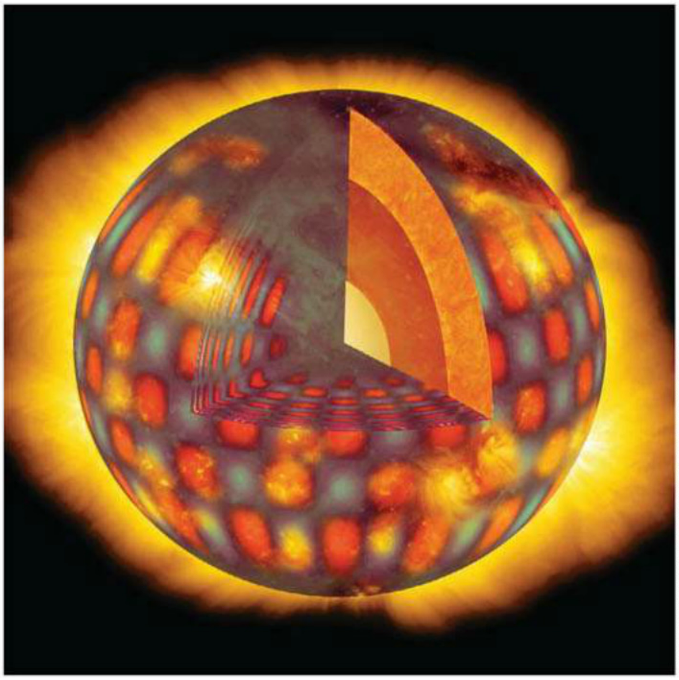
Jonathan Lunine
Cornell University, Ithaca, New York

Q: IF YOU COULD GET CLOSE ENOUGH TO THE SUN AND HANG OUT A MICROPHONE THAT WOULDN'T MELT, WOULD IT PICK UP ANY SOUND FROM OUR STAR?

Susan Newman
Richfield, Minnesota

A: Astronomers have been "listening" to the Sun's "humming" since 1960. But, if the solar system is a recording studio, keep in mind that it resides in a vacuum chamber. The Sun's music reaches us not as sound but as light. To record these solar "sounds," you must replace the microphone with a photometer or a spectrograph, which measures subtle changes in the brightness or wavelengths of sunlight due to solar vibrations.

The Sun vibrates like a musical instrument, similar to an organ. Instead of the room-temperature air in an organ pipe, though, hot hydrogen and helium gas, whose temperatures vary with depth, fills the Sun. Instead of a cylindrical pipe, our star is a sphere, its shape molded by gravity, with no solid container. And while an organist forces pressurized air into a pipe to make it resonate, natural turbulence in the gas near the Sun's surface causes its vibrations. This generates sound waves that travel into the Sun, are reflected when they reach its surface again, and cause the star to resonate in millions of frequencies.


SUN: SDO/NASA/AIA CONSORTIUM; OSCILLATIONS: NSO/AURA/NSF

The Sun has millions of internal oscillation modes, but they have frequencies too low for humans to hear. In this computer model of one solar oscillation mode, receding regions appear in red tones and approaching ones in blue. Astronomers measure the frequencies of such modes and use theoretical models to learn about the internal structure and dynamics of the Sun.

Astronomers record these frequencies, not for their interstellar iPods, but to probe the Sun's interior, the same way geophysicists use earthquake waves to study Earth's interior. Because of this parallel, the technique is called helioseismology.

The Sun's "loudest pitch" is about 0.0033 Hertz (Hz) — some 6,000 times below the lowest tone audible to a human ear. Music-minded astronomers take the frequencies of solar oscillations, multiply them by a million, and convert them into a soundtrack you can hear — although not quite the same as the microphone and sound system at a concert. But would the noise from the Sun's turbulence be loud enough and in the right frequency range to hear?

Loudness depends on how much the pressure changes at the microphone (or ear). At the depth from which visible light can first escape the Sun (a few hundred kilometers), the pressure fluctuations need be only 0.1 percent to be as loud as a chainsaw. But the pitch of a chainsaw's whine is about 4,000 Hz, a million times higher than the frequencies of the smallest turbulent eddies in supercomputer models of the solar atmosphere. Even if the Sun had waves a hundred meters from crest to crest, short enough to be the lowest audible pitch, you wouldn't hear it because there's no solid surface against which those waves could crash.

The shallows of the solar sea are indeed a noisy place, but not to human ears. The Sun is singing the sound of silence.

Jaymie Matthews
University of British Columbia, Vancouver

Send us your questions

Send your astronomy questions via email to: **askastro@astronomy.com**; or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

What's lurking in Lynx?

Whether you use a big or small scope, this oft-neglected constellation will dazzle you with its celestial targets.

by Michael E. Bakich

If you can't immediately conjure up the position of the constellation Lynx, I understand. It's not an iconic star figure like Orion or Scorpius. A good reasoned guess would place it in the winter sky (because this story is in the January issue). But, in fact, about half of Lynx lies directly north of Cancer the Crab, and the rest of the star pattern sits between the Big Dipper's bowl and the main part of Auriga the Charioteer. So you can observe it in the springtime, too.

Of the 88 constellations that cover the sky, Lynx ranks 28th in size but only 66th in overall brightness. It contains only one of the 200 brightest stars, and that one — magnitude 3.2 Alpha (α) Lyncis — barely makes the list at number 191.

Lynx is a northern constellation, but at least part of it is visible from earthly locations north of latitude 57° south. Observers located north of latitude 28° south can see the entire constellation. Both of these numbers, however, assume a perfect horizon. In practice, move 5° north in each case to assure good visibility.

This star pattern does not come to us from antiquity. German astronomer Johannes Hevelius, best known for his studies of lunar features, included Lynx (along with six other new star figures) in a celestial atlas of 56 engraved maps that accompanied his 1690 star catalog, *Firmamentum Sobiescianum, sive Uranographia, totum Coelum Stellatum*.

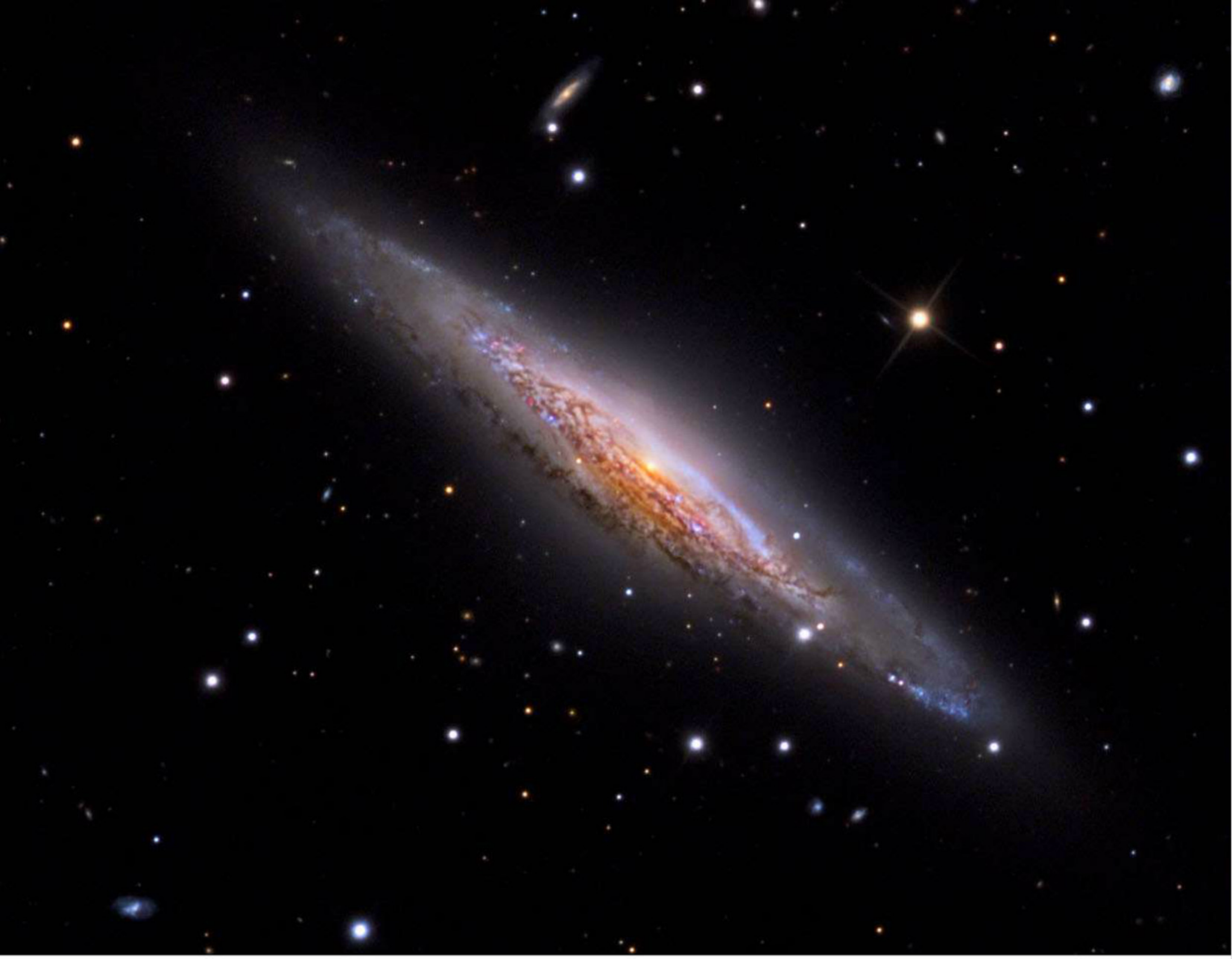
In the more than three centuries since this constellation's birth, astronomers have found numerous deep-sky targets within its boundaries. Most are dim galaxies too numerous to count and too faint to target with amateur telescopes. But enough bright targets lurk within Lynx to fill an evening observing session.

In this story, I'll describe 10 of my favorites, and I've included something for everyone. Small-scope users can enjoy a trio of nice double stars and a famous globular cluster. And large-scope owners can challenge both their optics and their sky conditions not only with individual galaxies, but also with clusters of those distant, massive star systems. In each section, the objects are in order of increasing right ascension, so the westernmost ones will rise first.

The Intergalactic Wanderer (NGC 2419) is one of the most distant globular clusters still tied to the Milky Way by gravitational attraction. The bright star closest to the cluster shines at magnitude 7.2. BERNHARD HUBL

Small-scope targets

As a constellation, Lynx can be difficult for beginning observers to find, so trying to locate a 5th-magnitude star in it can prove tough. The best star-hop to our first target, the triple star **12 Lyncis**, starts at magnitude 3.7 Delta (δ) Aurigae; the triple star lies 8.2° northeast of that sun. Once you do find it, even a small telescope easily will show the magnitude 5.4 blue-white A star



The UFO Galaxy (NGC 2683) lies some 16 million light-years from Earth. It has the classic shape of supposed extraterrestrial objects that terrified the uninformed throughout the 1950s. It shines at magnitude 9.8 ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

(the primary) with its magnitude 7.1 yellow (although some observers report seeing orange) C companion 8.6" away. Use a magnification around 100x for these two. Seeing the blue-white B component well requires double the magnification, though. Spotting it isn't a matter of brightness — it shines at magnitude 6.0. The separation, however, is much less than between A and C. B lies only 1.8" from the primary.

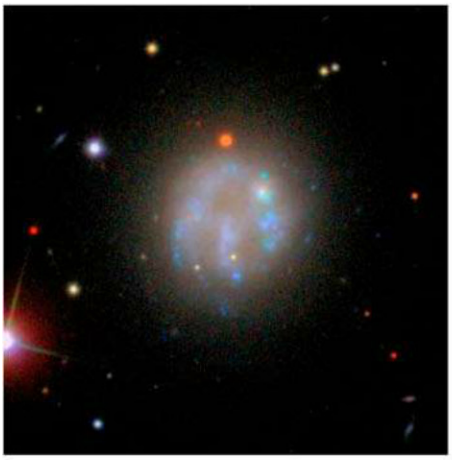
After enjoying the triple star 12 Lyn, move to the variable star **R Lyncis**, a red giant whose brightness changes by more than 7 magnitudes. Even at its brightest, however, you'll need a scope to see it.

To find R Lyn, point your telescope 9° east-northeast of Delta Aurigae. The star attains a maximum brightness of 7.2. It hits that peak every 387.75 days and should next be there in mid-August. At minimum, in early February (roughly 194 days before maximum), R Lyn should glow meekly around magnitude 14.3.

The next object, **19 Lyncis**, has a separation of 14.8", so it's a double star you can split through even a 2-inch telescope. The magnitude 5.8 primary shines sunflower yellow while the magnitude 6.7 secondary appears medium-blue. The easiest way to find this pair is to point your scope 10.5° west-southwest of magnitude 3.4 Muscida (Omicron [o] Ursae Majoris).

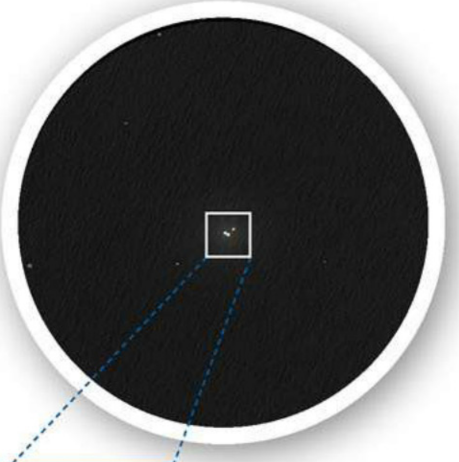
Our next treat, the **Intergalactic Wanderer** (NGC 2419), lies in a region of southwestern Lynx devoid of bright stars. To find this globular cluster, first locate magnitude 1.6 Castor (Alpha Geminorum) in Gemini the Twins and move 7° due north.

NGC 2419 isn't famous for its brightness (magnitude 10.4), size (4.1'), or beauty

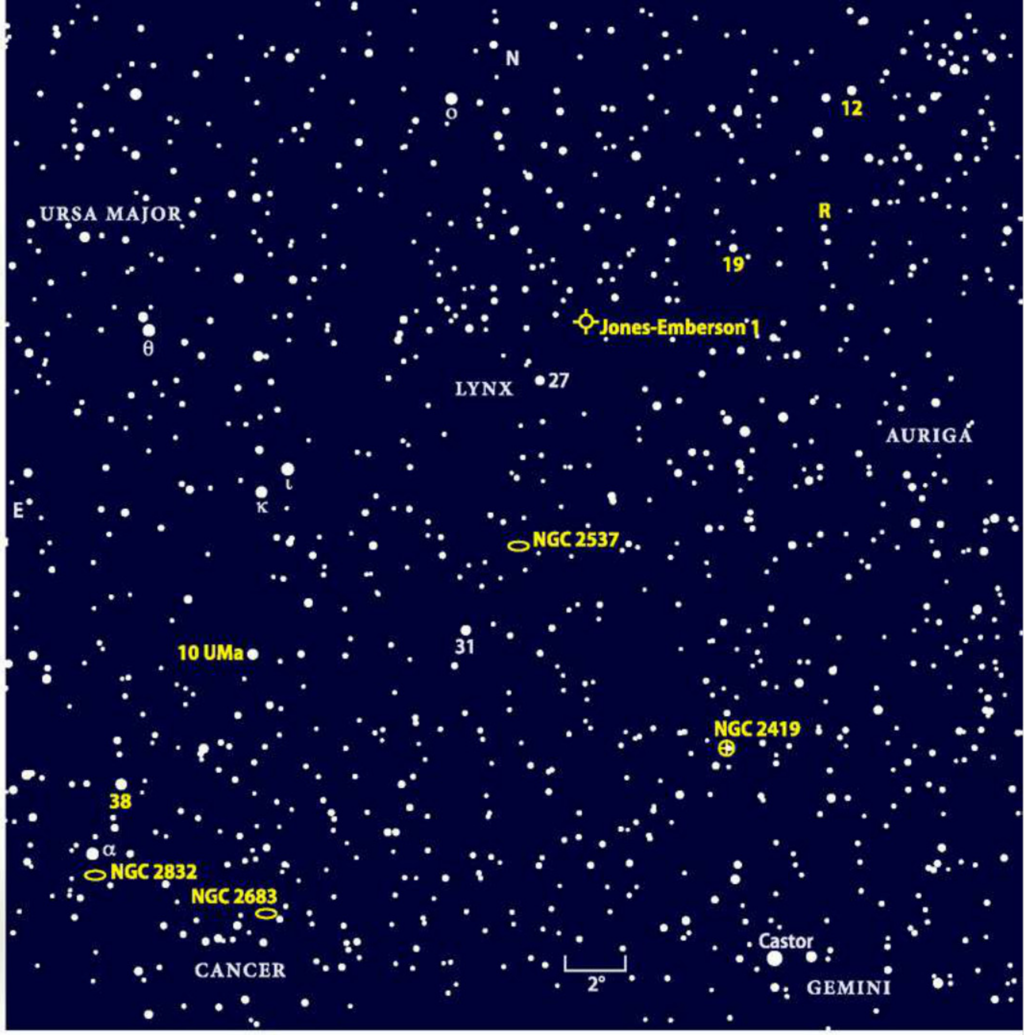


The Bear Paw Galaxy (NGC 2537) is a tough catch through even medium-sized telescopes. Be sure to use as high a magnification as you can when you observe this object. SLOAN DIGITAL SKY SURVEY

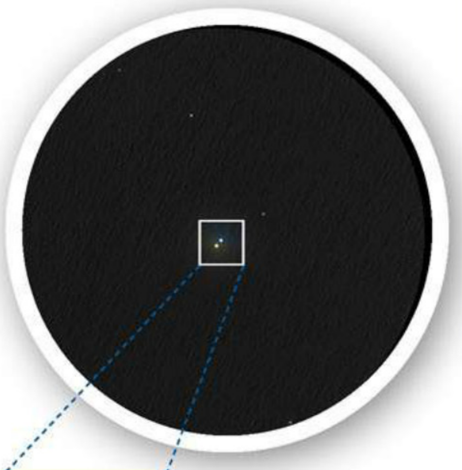
Michael E. Bakich *is an* Astronomy *senior editor and author of* 1,001 Celestial Wonders to See Before You Die *(Springer, 2010).*



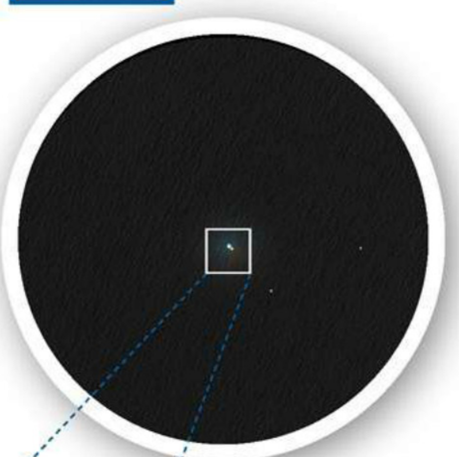

This sketch shows 12 Lyncis as a gorgeous triple star with a yellow-orange C component. You'll find it in the northwestern section of Lynx, near its border with Camelopardalis. JEREMY PEREZ



The constellation Lynx first appeared in 1690. It covers 545 square degrees, or about 1.3 percent of the sky. Use this chart to home in on the 10 targets discussed in this story. *ASTRONOMY*: RICHARD TALCOTT AND ROEN KELLY




This sketch of 19 Lyncis reveals a colorful target. Even the fainter bluish component, which lies 14.8" from the yellow primary, shines nicely at magnitude 6.5. JEREMY PEREZ




This sketch of 38 Lyncis shows the components as they appeared through a 6-inch f/8 Newtonian reflector. The double star lies 2.5° north of magnitude 3.1 Alpha (α) Lyncis. JEREMY PEREZ

through a telescope, but rather because it's one of the Milky Way's most remote globular clusters. It lies some 300,000 light-years from our galaxy's core and only 25,000 light-years closer to us. That places it more than 100,000 light-years beyond the Milky Way's most famous satellite galaxy, the Large Magellanic Cloud, and even farther away than the Small Magellanic Cloud.

Astronomers christened it the Intergalactic Tramp, then the Intergalactic Wanderer (was the change because "tramp" is now a politically incorrect word?), because they thought its position placed it in the space between galaxies. We now know that gravity binds NGC 2419 to the Milky Way, although it takes some 3 billion years to complete one orbit.

A 4-inch telescope reveals NGC 2419, but you won't see much detail. Through an 8-inch or larger scope at 200x or above, look for an ever-so-slightly brighter center ringed by an irregularly lit halo. Despite the lack of details, seeing the most distant globular visible through most amateur instruments makes the Intergalactic Wanderer a worthy catch.

Just for fun, take a look at the magnitude 4.0 star **10 Ursae Majoris**. You'll find it 6° northwest of the almost identically bright 38 Lyncis, which shines at magnitude 3.8. I'll describe that star below. English astronomer John Flamsteed cataloged 10 UMa in the early 18th century. Since then, however, this star's proper motion (movement across our line of sight) has carried it across the border into Lynx — yet it still retains its "UMa" designation.

The third and final double star I'll discuss is **38 Lyncis**. Look for it in a no-man's land of faint stars not quite 2.5° north of Alpha Lyncis.

Unlike our previous two colorful pairs, each of the stars in this binary appears white. Their magnitudes are 3.9 and 6.1, a difference that makes the primary 7.6 times brighter than the secondary. The separation is close — 2.7" — but even a 4-inch scope will split them. For best results, crank the magnification past 150x.

Large-scope targets

With brightness estimates ranging from 12th to 14th magnitude and a diameter of

some 400", planetary nebula **Jones-Emberson 1** (PK 164+31.1) admittedly makes a better target for imagers than observers. But when has that stopped us before? In fact, through telescopes with apertures above 16 inches and the addition of an Oxygen-III filter, you'll see a surprising amount of detail.

To locate this elusive object, first find the magnitude 4.8 star 27 Lyncis, and then aim your scope 2.5° northwest. Although images show a complete gaseous ring with two opposing bright spots, you'll see only part of the ring through the eyepiece. This fact gives PK 164+31.1 its alternate name — the Headphone Nebula.

Next, head 8° south-southeast of Jones-Emberson 1 to the **Bear Paw Galaxy** (NGC 2537). Because of its common name, you might guess that it will display some structure. That's true, but only through the largest backyard scopes. To find it, first target the magnitude 4.3 star 31 Lyncis and head 3.3° north-northwest.

Visually, this magnitude 11.7 galaxy displays alternating bright and dark regions within a 1.7' by 1.5' diameter oval. The three main bright areas separated by the dark "U" that wends through the object form the bear's "toes." If you don't spot them initially, crank up the magnification as high as sky conditions allow.

Our next object is the **UFO Galaxy** (NGC 2683). This is a classic edge-on spiral that orients exactly northeast to southwest. To find it, point your scope 4.8° north-northeast of magnitude 4.0 Iota (ι) Cancri.

The UFO Galaxy's common name derives from the resemblance of its shape to descriptions of unidentified flying objects from the 1950s. It appears more than three times as long as it is wide with an extended, bright central region.

You can spot magnitude 9.8 NGC 2683 through a 3-inch telescope from a dark observing site because it's not tiny, measuring 8.4' by 2.4'. To pull out its details, however, you will need a bigger scope.

The faint spiral arms show alternate dark and bright patches called mottling through a 12-inch instrument at powers above 300x. Through larger scopes, you'll notice that the northeastern arm extends a bit farther than the southwestern one.

A great object to end your observing session in Lynx is elliptical galaxy **NGC 2832**, which resides in the galaxy cluster Abell 779. You'll find that group less than 0.7° south-southwest of Alpha Lyncis. But finding its position and seeing it well are two different things. At magnitude 11.9, NGC 2832 is the brightest member of the cluster. It has an oval shape and measures 50 percent longer than it is wide oriented roughly northwest to southeast. Its given dimensions are 3.0' by 2.1'.

If you have access to a 16-inch or larger telescope, study the area around NGC 2832 to see how many other faint galaxies you can spot. The magnitude 13.4 elliptical galaxy NGC 2831 lies only 24" to the southwest. Even fainter, the magnitude 13.9 lens-shaped spiral NGC 2830 lies a bit more than 1' to the west-southwest.

Want more? Abell 779 is chock full of faint targets. Just 5' west of NGC 2832 lies magnitude 14.4 NGC 2825, and magnitude 14.5 NGC 2834 lies 4' southeast of our starting point, NGC 2832.

Jones-Emberson 1 (PK 164+31.1) is a large planetary nebula with low surface brightness. Large amateur telescopes reveal the two bright regions that caused amateur astronomers to dub it the Headphone Nebula. You'll see more detail if you use an Oxygen-III filter. STEVE CANNISTRA

DEEP-SKY TREATS IN LYNX

Object	R.A.	Dec.	Type	Mag.	Size/Separation
12 Lyncis	6h46m	59°26'	DS	5.4/6.0/7.1	1.8"/8.6"
R Lyncis	7h01m	55°20'	VS	7.2–14.3	—
19 Lyncis	7h23m	55°17'	DS	5.8/6.7	14.8"
NGC 2419	7h38m	38°53'	GC	10.4	4.1'
Jones–Emberson 1	7h58m	53°25'	PN	12.4	400"
NGC 2537	8h13m	45°59'	CDG	11.7	1.5'
NGC 2683	8h53m	33°25'	SG	9.8	8.4' by 2.4'
10 Ursae Majoris	9h01m	41°47'	S	4.0	—
38 Lyncis	9h19m	36°48'	DS	3.9/6.1	2.7"
NGC 2832	9h20m	33°45'	EG	11.9	3.0' by 2.1'

Key: R.A. = Right ascension (2000.0); Dec. = Declination (2000.0); Mag. = Visual magnitude; CDG = Compact dwarf galaxy; DS = Double star; EG = Elliptical galaxy; GC = Globular cluster; PN = Planetary nebula; S = Star; SG = Spiral galaxy; VS = Variable star

Show off a little

Hopefully, finding and observing these objects will diversify your skywatching during the Northern Hemisphere's coldest season. And you may enjoy the added treat of someone wandering over during a star party, sighting along your scope's tube, and asking, "What are you looking at?" Your answer will identify you as an observer who knows that more objects exist in the winter sky than the Orion Nebula.

Will Comet ISON be a superstar?

Few comets in history have received the adjective **great**. *Comet ISON may become one of them.* **by Michael E. Bakich**

Throughout history, few celestial events have garnered as much attention as bright comets. From ancient times until the invention of the telescope in 1608, most earthlings considered them harbingers of doom. Some even claimed they were the finger of God, pointing toward mankind to warn of a future calamity.

We've come a long way since then. Now such appearances bring only good news: Telescope sales multiply, astronomy clubs increase membership, and science magazines expand circulation. But the Northern Hemisphere (where most manufacturers, clubs, and magazines are located) hasn't seen a bright comet since C/1995 O1 (Hale-Bopp) shone in the sky in early 1997. Well, to quote Janine Melnitz (played by actress Annie Potts) in *Ghostbusters*: "We got one!"

ISON vs. Kohoutek

Less than a year from now, Comet C/2012 S1 (ISON) may well become the brightest comet anyone alive has ever seen. That's right, I said it. If that statement makes you tense up a bit, you're probably old enough to remember American astronomer Carl Sagan's appearances on *The Tonight Show*, as he talked about Comet C/1973 E1 (Kohoutek) with host Johnny Carson. What you may not remember is that Sagan wasn't just pulling predictions out of thin air. He based them on cold, hard science.

First, Kohoutek's orbit indicated that it was a pristine object from the Oort Cloud (a region of billions of comets 50,000 times as far from the Sun as Earth) and that it had never approached the Sun before. As such, astronomers believed it contained enough material to form an immense coma (the gaseous envelope around the main comet body). It would, therefore, reflect enough sunlight to make it appear spectacular.

Second, at perihelion (the closest approach to the Sun) Kohoutek would pass only 0.14 astronomical unit from our star. One astronomical unit (AU) is the average distance between the Sun and Earth, about 93 million miles (149.7 million kilometers). Because comets are brighter the closer they lie to the Sun, this seemed a good omen.

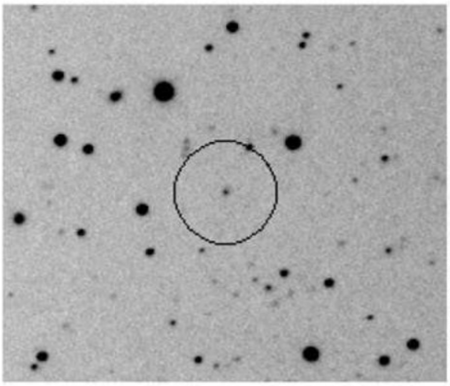
Unfortunately, Kohoutek's composition was such that it partially disintegrated at perihelion. So Sagan's predictions of a bright comet fell short, which begs the question: Could that happen to Comet ISON? Indeed, how bright it will get is currently the subject of vigorous discussion among planetary scientists.

Michael E. Bakich *is a veteran comet-watcher and author of* 1,001 Celestial Wonders to See Before You Die *(Springer, 2010).*

What's in a name?

Astronomers Vitali Nevski from Vitebsk, Belarus, and Artyom Novichonok from Kondopoga, Russia, discovered the comet on images they obtained September 21. They used the 16-inch (0.4-meter) Santel reflector at Kislovodsk Observatory, part of Russia's International Scientific Optical Network. That abbreviation — ISON — is now Comet C/2012 S1's common name.

When the two scientists found the comet, it glowed weakly at magnitude 18.8. As a comparison, it would take the light from more than 100,000 such comets to equal the faintest star visible to the naked eye from a dark site. So, they weren't convinced it was a comet. The following night, they obtained additional images through the 1.5-meter Ritchey-Chrétien reflector at Maidanak Observatory in Uzbekistan.



V. NEVSKI/A. NOVICHONOK

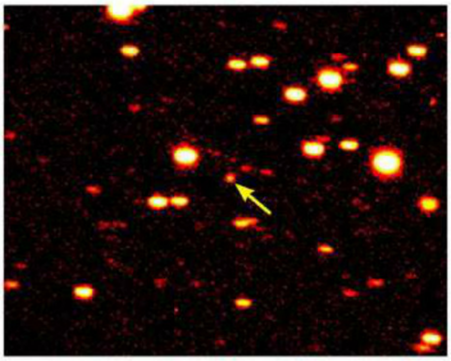
C/2012 S1 (ISON) lies in the center of the circle in the discovery image taken September 21, 2012. This photo combines five 100-second exposures through a 16-inch f/3 reflector.

But that 24-hour span allowed other observers to track down the comet as well. Had the discoverers reported it the first day, we'd call it Comet Nevski-Novichonok. Instead, rules that the International Astronomical Union — the science's governing body — established years before dictated that its name would be ISON.

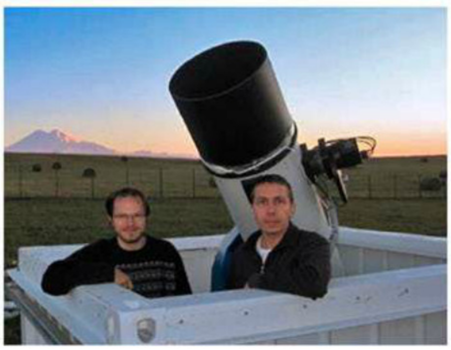
Cold, hard science

Here's what astronomers know. Comet ISON will approach to within 0.012 AU of the Sun's center November 28/29, 2013. (The date will be the 28th in the Western Hemisphere.) That means it will lie only 680,000 miles (1.1 million km) from our star's surface.

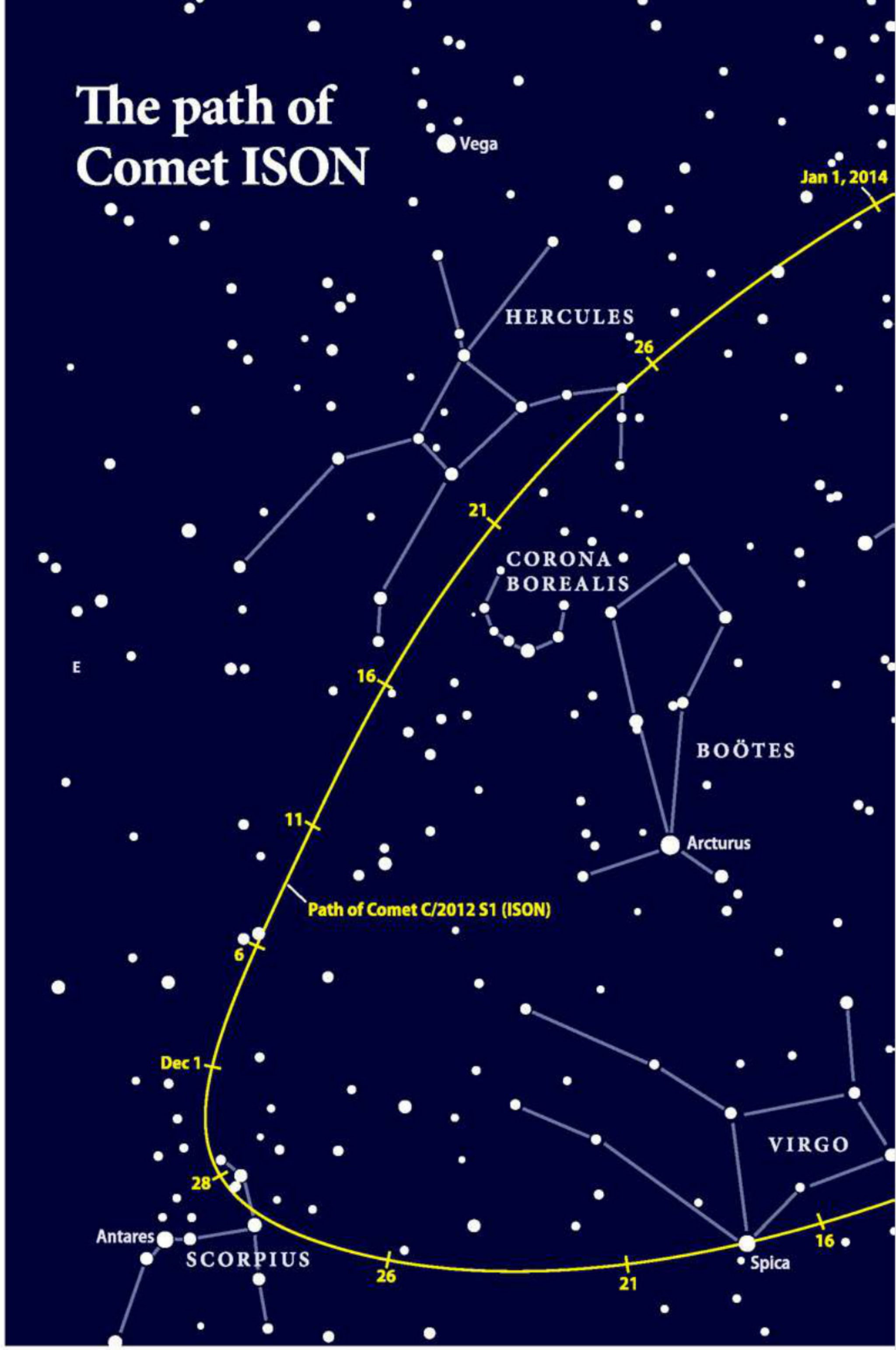
Then, on December 26, the comet will reach perigee, its closest approach to Earth. At that time, it will lie 0.43 AU away. And



Comet C/2012 S1 (ISON) appears as a faint blob (arrow) in this image taken September 22, 2012, at the Remote Astronomical Society Observatory near Mayhill, New Mexico. REMANZACCO OBSERVATORY/ERNESTO GUIDO/GIOVANNI SOSTERO/NICK HOWES



Artyom Novichonok (left) and Vitali Nevski discovered C/2012 S1 (ISON) on September 21, 2012. They confirmed its cometary nature the following night. ARTYOM NOVICHONOK



here's an opening volley aimed at doomsayers: The comet will come no closer to us than this distance. It won't hit Earth, and its only effect will be to dazzle humanity as a flaming scimitar splayed across the sky.

Comet ISON's orbit greatly resembles that of C/1680 V1 (Kirch), also known as the Great Comet of 1680. If these two objects are part of the same parent body, we have several reasons to celebrate. First, Kirch's Comet was one of the brightest comets of the 17th century, visible in the daytime. Second, at perihelion it stood only half as far from the Sun as ISON — and survived. Third, its perigee distance of 0.42 AU is almost exactly that of ISON's.

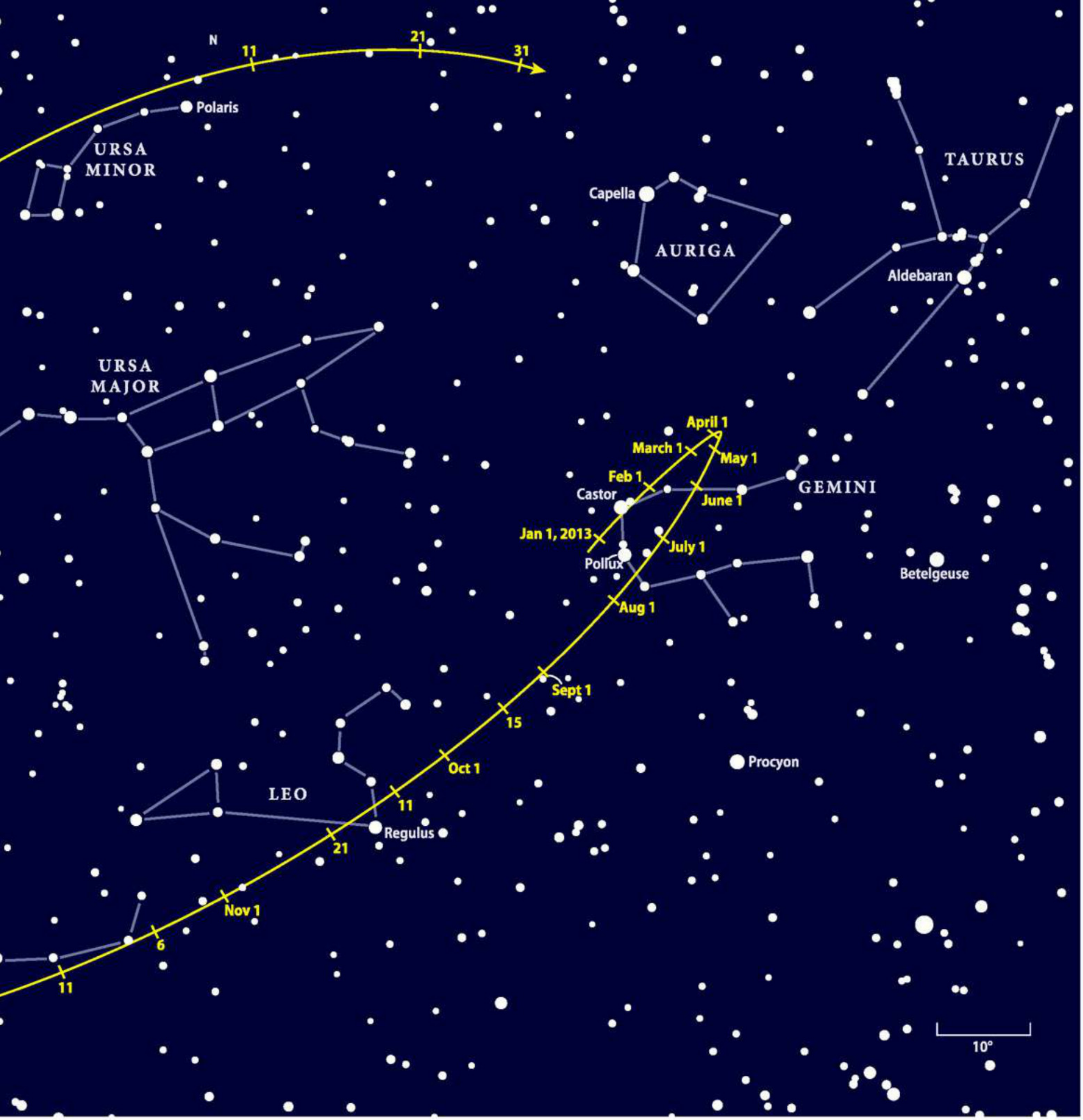
Visibility

Your chances of seeing Comet ISON increase as we head toward fall 2013. If you want to try for it now, however, head out January 11 (the year's first New Moon). Comet ISON will lie 1.3° east-southeast of Castor (Alpha [α] Geminorum) in Gemini the Twins. At approximately 16th magnitude, it should glow brightly enough for amateur astronomers with 24-inch or larger scopes and good finder charts to spot. And a CCD camera attached to an 8-inch scope easily will produce an image of ISON.

That said, the comet will not show much detail for several months. By late summer, you should be able to spot the magnitude 11 comet through a 4-inch telescope. Binoculars will come into play in early October when ISON's magnitude hits single digits. And sometime around Halloween, C/2012 S1 should cross the naked-eye threshold for those at a dark site.

Five days later, it hits magnitude 6. Five more days — magnitude 5. Five more — magnitude 4. Then it jumps a magnitude every three days (or less). On November 25, ISON begins to shine at negative magnitudes. It will be fascinating to watch these brightness changes visually or to document them via astroimaging.

On November 28, when the comet is at perihelion, ISON may shine more than a hundred times as brightly as Venus, normally the most brilliant "starlike" object in the sky. Amazingly, it may reach or even exceed magnitude –12.6 — the brightness of the Full Moon.



C/2012 S1 (ISON) reaches perihelion (closest to the Sun) November 28 and perigee (closest to Earth) December 26. *ASTRONOMY*: RICHARD TALCOTT AND ROEN KELLY

Unfortunately, on that date it stands only 1.3° northeast of our daytime star. And while the Sun's glare surely will hide it from casual observers, dedicated amateurs who carefully shield the Sun will be able to view ISON throughout the day.

After reaching perihelion, Comet ISON crosses into the northern part of the sky December 8. It should remain brighter than a 1st-magnitude star through December's first week but with a spectacular tail. Its position near the celestial equator will allow observers all over Earth to see it, but those in the Northern Hemisphere will get increasingly better views as Christmas approaches. In fact, on January 8, 2014, ISON (then near 6th magnitude) will lie only 2° from Polaris (Alpha Ursae Minoris).

Start making plans

Astronomy and Astronomy.com will cover Earth's encounter with Comet ISON in great detail in the coming year. If it's even one-hundredth as bright as many expect it to be, those of us in the astronomical community need to be ready. The nattering nabobs of negativism already are downplaying expectations. I, for one, am not drinking from their half-empty glass. So let them compare my predictions with those for Kohoutek. Do you really think I'll complain if they mention me in the same sentence as Carl Sagan?

Astronomy tests the Canon 60Da

Higher resolution, heightened red sensitivity, and other features make this DSLR the new standard for astroimaging.

by Jack Newton

PRODUCT INFORMATION

Canon EOS 60Da DSLR
Sensor: High-sensitivity CMOS chip
Pixels: 18 million pixels (5200x3462)
ISO range: 100 to 12800
Shutter speed: 1/8,000-second to 30 seconds (plus bulb)
LCD monitor: 3-inch color, with 1.04 million pixels
Power source: Battery pack LP-E6 (AC adapter optional)
Includes: Rechargeable battery; plug-in power supply; Remote Controller Adapter; stereo audio-visual cable; software
Price: $1,499
Contact:
Canon U.S.A.
One Canon Plaza
Lake Success, NY 11042
[t] 800.652.2666
[w] www.usa.canon.com

When I heard that Canon had released the EOS 60Da, a digital single-lens reflex (DSLR) camera especially designed for astroimaging, I couldn't wait to get my hands on it. Because I had reviewed the Canon 20Da (in the July 2006 issue of *Astronomy*) when the company introduced it, I was able to compare the performance of both versions for this story.

Canon offers the 60Da as a camera body only (no lens), although it is compatible with the company's family of EF and EF-S lenses. The camera package includes a rechargeable battery, a plug-in power supply, the Remote Controller Adapter RA-E3, an AVC-D400ST stereo audio-visual cable, software disks, and an operating manual.

The *a* is for "astronomy"

The EOS 60Da contains an 18-megapixel CMOS 5200x3462 sensor that produces a 102-megabyte RAW image. It features an improved infrared-blocking filter compared with the 20Da.

The company also expanded the wavelength response to include the Hydrogen-alpha (Hα) line. This change provides a threefold increase in Hα sensitivity over the sensor in Canon's 60D model and adds a lot more of the natural red color to shots you'll take of emission nebulae.

Canon's EOS 60Da is a DSLR model the company designed specifically for astroimagers. It has extended red sensitivity and several noise-reduction features sky photographers will find valuable. *ASTRONOMY*: WILLIAM ZUBACK

One feature I really like is the Vari-angle 3.0-inch Clear View LCD Monitor, which you easily can reposition and rotate 180°. This not only removes a potential heat source from the CMOS sensor, but it also greatly improves the viewing capability.

The 60Da's viewing screen has 1,040,000 "dots" that you can use in "Live View" mode. I have used many different telescopes for imaging, and on some of them a fixed-view camera required me to lie in a prone position to see the screen.

When you place the 60Da in "Live View" mode with the stereo AV cable attached to a television monitor, you can display what's on the viewing screen in glorious high definition (1920 pixels by 1080 pixels). What fun it is to focus the camera using such a large format. This setup also is great for star parties because many onlookers can enjoy live views on the monitor simultaneously.

More features

Part of the 60Da's new sensor design includes advanced adjustable noise reduction, which you can improve by taking a dark-frame exposure of the

Jack Newton *is a contributing editor of* Astronomy, *a supernova discoverer, and a longtime DSLR astroimager.*


JACK NEWTON

Compare these images of the North America Nebula (NGC 7000). The one on the left, made six years ago, combines 60 minutes of exposures through the Canon 20Da. The right image is a single 4-minute exposure at ISO 6400 taken through the Canon 60Da. The author used the same telescope and focal ratio for both.

same duration as your main shot immediately after it. When subtracted from the main image, the dark frame removes the thermal noise, hot pixels, and bias (brightness irregularities among the CMOS' pixels) from the image. You can activate this feature in the "Custom Functions" menu under "Long exposure noise reduction."

A "High ISO speed noise reduction" menu also is available when you set the camera in auto mode. And you might need it. The ISO in the 60Da now ranges between 100 and a whopping 12800.

For exposures longer than 30 seconds, Canon's optional Timer Remote Controller TC-80N3 will permit multiple timed exposures. Later, you can use software to stack the images you acquire to improve the quality of the final picture.

Please note that I have mentioned only those features pertaining to astroimaging; the 60Da offers dozens of other features for conventional photography.

Under the stars

Out of the box, the 60Da looks similar to the 20Da, but I learned quickly that there was a big difference in how each camera performs. For my first field test, I chose the Milky Way as a target.

I attached a 10mm lens to the 60Da, added a cable release, and placed the camera on a tripod. I set it on manual, activated the "Long exposure noise reduction" option, set the lens to f/3.5, selected an ISO of 6400, and took a 30-second exposure. When I examined it, the stars appeared as pinpoints from edge to edge.

I then moved into my observatory, where my 4-inch apochromatic refractor resides. I attached the 60Da using a 2" Canon adaptor ring and used the "Live View" mode to focus on the star Deneb (Alpha [α] Cygni). I can't say enough good things about being able to adjust the angle of the Vari-angle screen to provide a comfortable position for easy focus.

My target was the North America Nebula (NGC 7000). I set the 60Da to ISO 6400 and took a 4-minute unguided exposure. Then came the comparison. The new image was denser than one I had produced from a stack of five 12-minute exposures taken with the 20Da six years earlier.

For a change of pace, the next object I imaged was the Sun, and for the main optical component I used a solar telescope with a double-stacked Hα filter.

This time I moved the Vari-angle LCD monitor 90° from the Sun's position to remove any oncoming glare and allow myself to view solar prominences that easily snapped into focus. I set the camera to ISO 200 and bracketed exposures from $1/125$ to $1/60$ second. I later used this setup to capture May's annular eclipse of the Sun, with pleasing results.

The new standard

During the time I was testing the camera, one of my observing buddies handled it for less than five minutes. As he was placing it on the table with his left hand, he was ordering one for himself with the cellphone held in his right!

Indeed, the Canon 60Da should be a must-have for any astroimager wishing to take fabulous images through a DSLR. Its ease of use, special features, and spectacular results are likely to make it a market leader for many years to come.

The Vari-angle 3.0-inch Clear View LCD Monitor features 1.04 million pixels and 180° rotation for easy viewing while focusing. *ASTRONOMY*: WILLIAM ZUBACK

OBSERVING BASICS

BY GLENN CHAPLE

A backyard asteroid mission

You can't capture the detail of the Dawn mission, but observing its targets is a thrill nonetheless.

In the early hours of September 27, 2007, a Delta II rocket lifted off its launch pad at Cape Canaveral in Florida. It was the first day of the Dawn mission, an ambitious undertaking by NASA to send a spacecraft to the two most massive members of the asteroid belt — Ceres and Vesta. Dawn arrived at Vesta on July 16, 2011, orbiting and studying the Arizona-sized asteroid for more than a year. On September 5, 2012, the ion-propelled craft bid adieu to Vesta and began its journey toward a Ceres encounter in 2015.

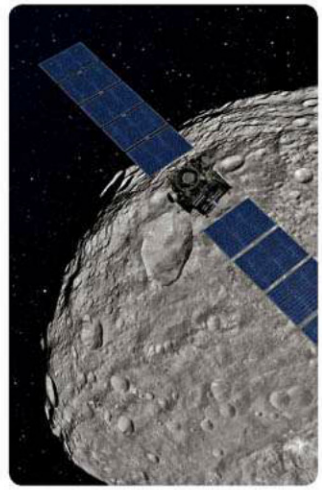
What would prompt NASA to incur the expense of a mission to two asteroids, instead of one? They're all the same, right? Not really. The 2006 International Astronomical Union's redefinition of solar system bodies elevated the much larger and more spherical Ceres to dwarf planet status. Vesta remained an asteroid — more specifically, a minor planet.

The differences, however, go beyond mere definition. Vesta is a rocky body similar in makeup to the inner planets. Ceres, on the other hand, appears to have an icy composition comparable to the moons that occupy the outer solar system. Both likely have changed little since the early stages of solar system formation. Studying two dissimilar bodies that originated in the gap between Mars and Jupiter may provide important clues about the formation of the planets.

During its visit, Dawn mapped Vesta's surface, studied its composition, and analyzed its internal structure. Among the discoveries was a 310-mile-wide (500 kilometers) impact basin — subsequently named Rheasilvia — occupying much of Vesta's south pole. Near the crater's center, Dawn imaged a mountain nearly three times as tall as Mount Everest. The spacecraft's cameras also captured an intriguing series of grooves girding Vesta's equator, possibly a result of the impact that formed Rheasilvia.

The asteroid's varied surface composition and a differentiated (layered) interior that includes a basaltic crust and iron core indicate that Vesta is more than your run-of-the-mill asteroid. Indeed, researchers now consider Vesta a "protoplanet" not unlike Earth during the early stages of its formation. What will Dawn reveal about Ceres? Stay tuned!

At its conclusion, the Dawn mission will have consumed the better part of a decade. But you can accomplish your own asteroid mission in an hour or less using a telescope instead of a Delta II rocket. In January, both Vesta and Ceres are conveniently located in the constellation Taurus. Vesta flirts with Aldebaran (Alpha [α] Tauri) and lies a degree away from Epsilon (ε) Tauri at month's end. Ceres is a short star-hop from Beta (β) Tauri. Time to launch!



NASA's Dawn spacecraft, as depicted in this artist's rendering, spent a year studying the asteroid Vesta and is now en route to the dwarf planet Ceres. You can complete a telescopic Dawn mission in January when the two objects both lie in the constellation Taurus. NASA/JPL-CALTECH

The finder chart on page 43 of this issue's "The Sky this Month" will help you navigate your way to Vesta and Ceres. Your prime launch window will occur during the first half of January. At this time, the Moon is either absent from the evening sky or not yet bright enough to interfere with your observing. Pair your telescope with a low-power eyepiece; its wide field of view will embrace a larger chunk of sky than would a high-power ocular, making a star-hop search easier.

The journey ends when you encounter what appears to be two 7th-magnitude "stars" in the locations indicated on the chart. Don't bother switching to higher powers. Vesta and Ceres are so small and remote that they appear starlike when viewed with backyard scopes, no matter how high the magnification. To be absolutely sure you've spotted the two, make follow-up observations a night or two later. If the "stars" have moved, you've officially captured Vesta and Ceres and completed your Dawn mission.

Your voyage to Vesta and Ceres may seem underwhelming when compared to what the Dawn mission has revealed — all you get to see are ordinary stellar specks, while the spacecraft sent back spectacular close-up images of Vesta's cratered surface. Consider that the price tag for the Dawn mission runs nearly a half-billion dollars, and, upon completion of its mission, Dawn will have traveled 3 billion miles (5 billion km). Your telescope and accessories probably only set you back several hundred or thousand dollars, and you didn't even have to leave your backyard. Not a bad deal!

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: the dance of the spirits. Clear skies!

FROM OUR INBOX

Tap vs. torque

I recently read Glenn Chaple's discussion of Earth's precession under "Ask Astro" in the April issue (page 50). It was accurate, but his recall of basic physics terminology has slipped a bit.

A torque (a force acting in a manner that tends to cause a rotation), not a "tap," causes precession. If you remove the torque, the precession stops. In the case of a spinning top, gravity could cause a continuous torque if the center of gravity is not directly above (or below) the center of support. If you "tap" the axle of a top that is undergoing precession, it will exhibit a transient rapid "wobble" termed nutation.

As Chaple stated, the torque acting on Earth comes primarily from the Moon tugging on the equatorial bulge. (It pulls more strongly on the near side of the bulge.) The torque varies depending on the Moon's position and would be at maximum when Earth tips either toward or away from the Moon.

— Bob Bird, professor of physics (retired), Miami Dade College, Florida

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BY KARRI FERRON

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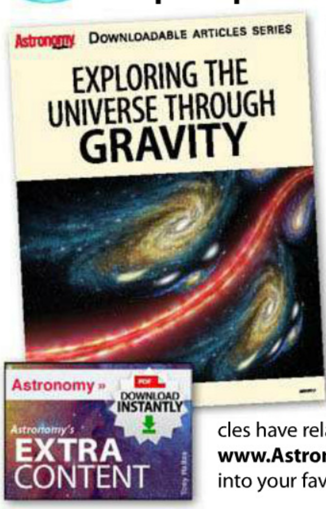

Have you ever read a magazine article and found the material so interesting that you wanted to learn more? Or had a topic trigger a memory of a previous story that you wished to explore again? *Astronomy*'s editors experience the same feelings, so we're giving readers a way to expand their knowledge.

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OBSERVING TOOLS

Astronomy's "Sky Guide 2013"

Subscribers can start planning for important 2013 observing events with exclusive access to a PDF version of *Astronomy*'s "Sky Guide 2013," which is available on newsstands with this issue. In 16 pages, get a month-by-month synopsis of what's in the night sky and learn about the year's most exciting attractions. Download this handy digital guide now at **www.Astronomy.com/skyguide**.

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COSMOS**IMAGING**

BY TONY HALLAS

"Hubba hubba" Hubble

Doing a little more work can turn an ordinary astroimage into a knockout.

Let's say you just imaged some obscure nebula in narrowband under the Full Moon. For our purposes, we'll work on NGC 7822 using a set of 5-nanometer (nm) Hydrogen-alpha ($H\alpha$), 5nm Sulfur-II (SII), and 3nm Oxygen-III (OIII) filters. These three choices constitute what imagers call the Hubble palette because the famous space telescope's images often use the same filters.

You've already stretched the data, converted it into visible colors ($H\alpha$ mapped to green, SII to red, and OIII to blue), and combined them using layers and clipping masks in *Photoshop*'s "Lighten Mode." This allows you to adjust the strength of each individual contributor for maximum effect. At this point — before adding RGB star colors — you probably have something that looks like Photo 1.

You might be content with this result, but it likely looks a little bland. Wouldn't it be nice if we could somehow make the colors more lively and, most importantly, get them to appear more distinctly to show a better representation of the narrowband signatures? As it turns out, we can. All it takes is two basic *Photoshop* techniques: converting to "Lab Color" to saturate the colors and using "Selective Color" to emphasize their differences.

First, open your 16-bit TIFF photo and go to "Image" > "Mode" > "Lab Color." *Photoshop* then separates your image into its luminance and color components. Use an "S" curve in "Curves" (see my February 2012 column) to increase the color saturation of your image. Then, convert the image back to RGB. Note that the amount of saturation will be equal to the intensity of the "S" curve that you generated in "Curves." The result should look something like Photo 2.

Now, here is where you get to use some poetic license. In this case, we want to use the Hubble palette but at the same time create as much difference as possible between the colors. Open your post-"Lab Color" photo and select "Image" > "Adjustments" > "Selective Color." After taking a good look at the basic colors of the image, you can emphasize and "cultivate" each one. Here's what I did:

CYAN = cyan +40, magenta –40, yellow –40, black –10.

YELLOW = cyan –40, magenta +0, yellow +40.

BLUE = cyan +20, magenta –30, yellow +40, black +10.

GREEN = magenta –40, yellow +40, black –10.

MAGENTA = cyan +20, magenta –20, yellow +20, black +10.

These settings affected the targeted colors, making them stronger and removing any spurious colors I didn't want. The final result is Photo 3.

Remember, narrowband imaging is what you make of it. I hope this helps you free your imagination.

FROM OUR INBOX

The dark-night rabids

Astronomy could be considered one of the most dangerous hobbies: falling off ladders, hypothermia, and even being the victim of crime in a remote location all come to mind as hazards. This letter is a cautionary note for a lesser-known one.

In almost 30 years of observing under the stellar canopy, I had never experienced what happened one July weekend. Around 2:30 A.M, as I stood in my driveway looking up at the sky, I suddenly felt an impact on the side of my head. By its weight and velocity — and because no remnant lay on the ground — I deduced it must have been a bat. These animals are known for their pinpoint flying accuracy and ability to turn sharply, so I can only imagine that vertigo, a muscle cramp, attention deficit disorder, or a temporary echolocation dysfunction disabled its normally superior aerobatic ability. I am in the medical field, so I immediately realized the possible dangerous consequence of this incident: rabies.

The virus, within the saliva or other secretions, doesn't need a break in the skin to enter the human body and start the slow process of accessing and infecting the nervous system. Once manifest, the outcome is almost universally fatal.

I immediately contacted an infectious disease consultant and the state Health Department; we agreed prudence was necessary and to start the rabies vaccine right away.

I hope this story has made you aware of a less-known hazard of enjoying the beauty of the night sky. So, please, take the appropriate steps to ensure your safety. — **Dave Tosteson,** Chisago City, Minnesota

This image of NGC 7822 looks fine with the standard Hubble palette, although some might consider it a little bland. ALL PHOTOS: TONY HALLAS

Running the image through *Photoshop*'s "Lab Color" to increase color saturation helps make the colors more vivid, but one step remains to separate them more.

By using "Selective Color," you can tweak and "cultivate" each of your photo's basic colors, resulting in a much more dramatic image.

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Sky quality meter

Unihedron / Grimsby, Ontario, Canada

Unihedron's SQM-LU-DL Sky Quality Meter needs no computer connection. It records for 88 days at five-minute intervals using two AA batteries. A threshold feature collects data only after twilight.

Price: $249.99
[t] 905.945.1197
[w] www.unihedron.com

Barlow lens

Orion Telescopes and Binoculars
Watsonville, California

Orion's High-Power 1.25" 5x 4-Element Barlow Lens gives any eyepiece a quintuple-power boost. The Barlow's body is aluminum, and it has a rubber exterior. The fully multicoated unit weighs only 7 ounces (198 grams).

Price: $169.99
[t] 800.447.1001
[w] www.telescope.com

Equatorial mount

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iOptron's SmartEQ Portable GOTO GEM is a computer-controlled German equatorial mount with a nine-speed drive motor, 0.5" resolution, and a Vixen-style dovetail saddle. It weighs 6.2 pounds (2.8 kilograms).

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Alt-azimuth mount

Orion Telescopes and Binoculars
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Orion's AZ-4 Micro-Motion Altazimuth Mount controls both motion axes. The mount and steel tripod weigh just 7 pounds (3.2 kilograms), but they carry a 10-pound (4.5kg) load. It adjusts in height from 31 to 49 inches (0.8 to 1.2 meters).

Price: $149.99
[t] 800.447.1001
[w] www.telescope.com

Astroimaging guide

Jerry Lodriguss
Voorhees, New Jersey

A Guide to DSLR Planetary Photography, an e-book by astroimager Jerry Lodriguss, explains how to take and process photos of the Sun, Moon, and planets by recording video via the "Live View" feature of your Canon DSLR.

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ASTRO**SKETCHING**

BY ERIKA RIX

Target winter clusters

Editor's note: *With this issue we welcome Erika Rix, a visual observer who records what she sees at the eyepiece through sketching. Erika is co-author of* Astronomical Sketching: A Step-by-Step Introduction *and* Sketching the Moon: An Astronomical Artist's Guide, *both by Springer. Follow her tips starting with this monthly column, and in no time you'll spot more detail through your scope than you thought possible.*

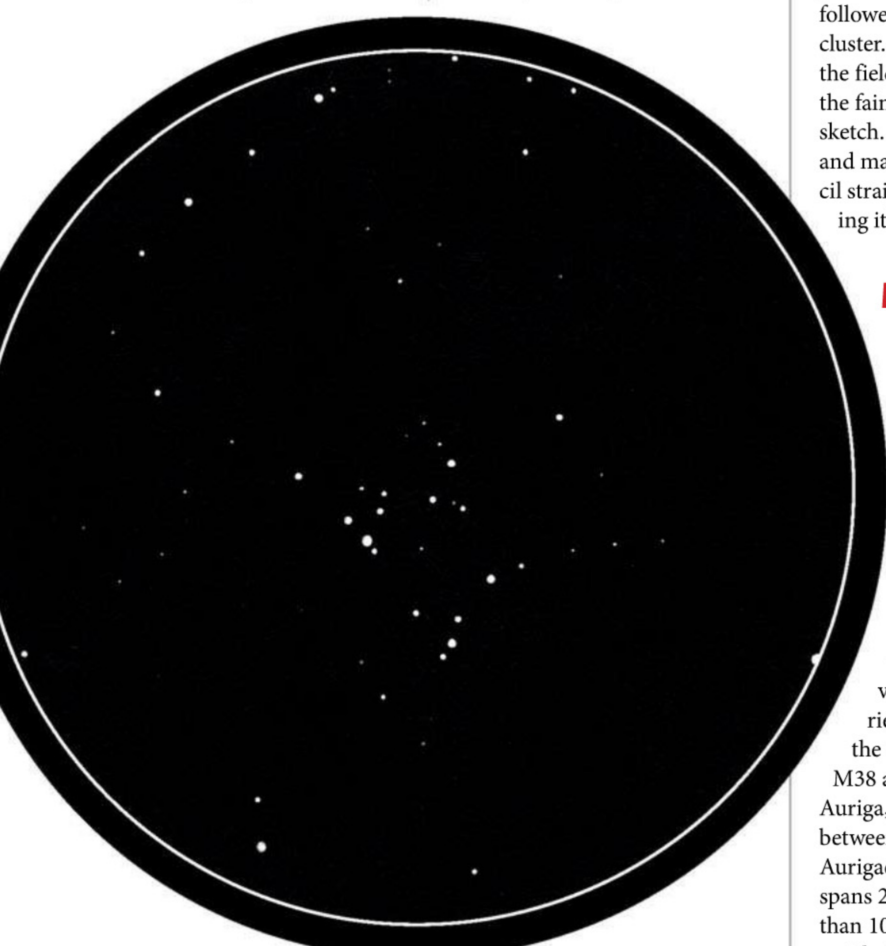
NGC 2169

Open clusters are a real treat, especially when they provide views that can spark our imagination, making them memorable by the shapes they form. A great example is NGC 2169 in Orion, which lies about 50' south-southeast of magnitude 4.4 Nu (ν) Orionis. This little gem, packed full of colorful single and double stars and patterns, measures 5' by 7'. From a sketcher's perspective, this object gently eases us into accurately rendering clusters and star fields without overwhelming us with an abundance of stars to plot.

Through binoculars, NGC 2169 looks like a small magnitude 5.9 trapezium. A 4-inch telescope at low power reveals two separate groups that resemble a pair of 7s with five or six stars in each.

The stellar groups transform into the number 37 at high magnifications. Large scopes reveal 30 cluster members. Look closely to see hints of color, and make sure to bump the magnification above 200x to split the double star Struve 848 within the cluster.

To sketch this little beauty, plot the brightest stars first, followed by the stars within the cluster. Work in wedges around the field of view, and then add the faintest stars to complete the sketch. For perfectly round stars and magnitudes, keep your pencil straight while slightly twisting it at various pressures.



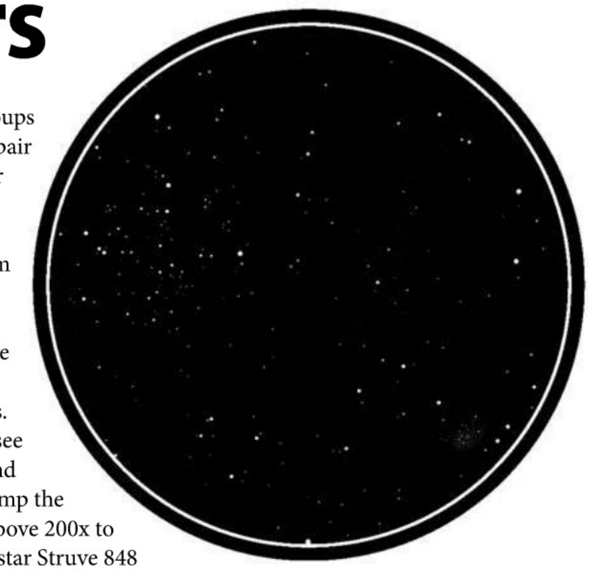
NGC 2169 in Orion, sketched by Erika Rix through a 6-inch f/9 reflector at 171x.

M38 and NGC 1907

Who hasn't been intimidated to sketch the famous Double Cluster (NGC 869 and NGC 884) in Perseus? If you fall into this category, then M38 and its southern companion, NGC 1907, are a perfect alternative that provides stunning views and sketching experience before you tackle the mighty Double Cluster.

M38 and NGC 1907 lie in Auriga, roughly halfway between Theta (θ) and Iota (ι) Aurigae. Magnitude 6.4 M38 spans 21' and contains more than 100 stars.

Chains of stars in M38 form an X or π shape stretching nearly 14' across. The cluster also sports several nice double stars and dark lanes. It's a magnificent, irregularly shaped object best viewed at low power that becomes richer in stars with increased aperture.



Open clusters M38 and NGC 1907 in Auriga, sketched by Erika Rix through a 6-inch f/9 reflector at 105x.

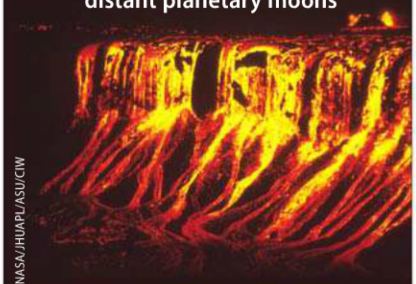
The other open cluster is NGC 1907. You can locate it 0.5° south-southwest of M38. NGC 1907 is small and faint by comparison, at 6' across and magnitude 8.2. It contains 10 stars you'll see within the hazy oblong backdrop of this cluster through a 4-inch scope. An increase in aperture and magnification will show close to 30 stars, some forming chains.

I drew both sketches at the eyepiece using an Astronomical League template, which you can download at http://tinyurl.com/ALsheet. I also used a #2 graphite pencil, a felt-tipped superfine Faber-Castell Pitt artist pen, and a 0.5mm mechanical pencil. Throughout the run of this column, I will invert black and white in my sketches to better represent what you'll see through the eyepiece.

COMING UP IN OUR NEXT ISSUE

TOUR OUR FIERY SOLAR SYSTEM

Hot spots, volcanoes, and geysers create a smorgasbord of volcanism from Mercury to distant planetary moons



NASA/JHUAPL/ASU/CIW

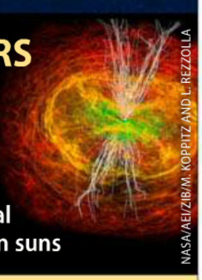
WHAT HALLEY'S COMET TAUGHT US

Find out why scientists consider it an object worthy of scrutiny

JACQUES GUERTIN

WHEN STARS GO BANG!

Some stellar explosions mark star death while others reveal greedy companion suns



NASA/AEI/ZIB/M. KOPPITZ AND L. REZZOLLA

PLUS

- Illustrated spread: Colors of our starry sky
- Sketching the Orion Nebula
- Sharing the stars with a new generation
- A beginners guide to star parties
- How to observe Jupiter
- All about Bushnell's new 5-inch reflector

Astronomy magazine

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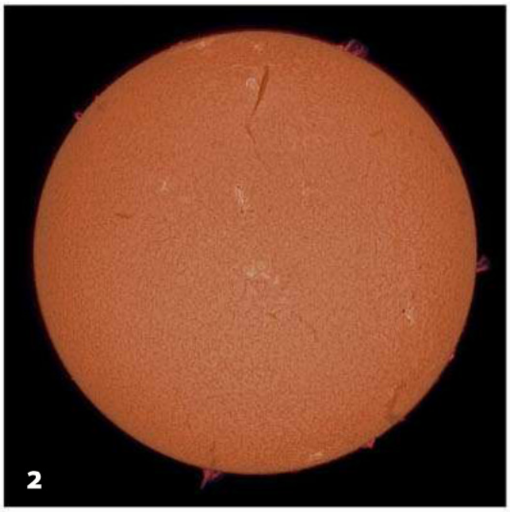
READER GALLERY


1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3

1. LBN 438
This dark nebula lies in a rich star field in the constellation Lacerta the Lizard. (10-inch Astro Systeme Austria ASA-10N Newtonian astrograph at f/3.6, FLI ML-8300 CCD camera, LRGB image with exposures of 460, 130, 130, and 130 minutes, respectively) • ***David Kopacz***

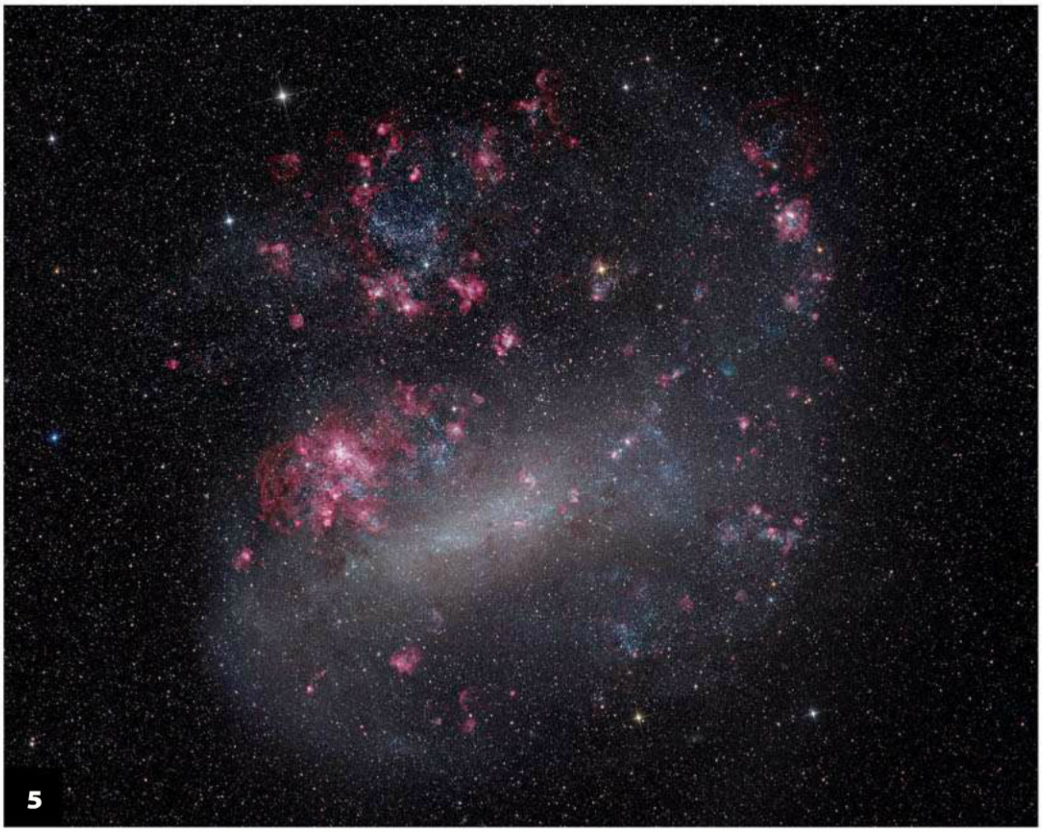
2. THE SUN
During solar maximum, prominences arch above our star's edge while whitish flares appear on its surface. (2-inch Solarview 50 Hα refractor at f/8, Celestron NexImage CCD camera, best 36 out of 6,000 frames, $\frac{1}{11}$- and $\frac{1}{120}$-second exposures, taken August 31, 2012, from Guelph, Ontario, Canada) • ***Ron Brecher***

3. NGC 5033
This spiral in Canes Venatici shines at magnitude 10.2. (5.6-inch Telescope Engineering Company TEC-140 apochromatic refractor at f/7, SBIG ST-8300M CCD camera, LRGB image with exposures of 320, 120, 120, and 120 minutes, respectively, taken remotely from the Rancho Hidalgo Equestrian and Astronomy Village near Animas, New Mexico) • ***Bernard Miller***

4

4. SOUTH WINDOW ARCH
This landmark in Arches National Park, Utah, makes a great foreground setting for star trails. During this photo shoot, the imager experienced wind gusts of up to 50 mph (80 km/h). (Nikon D700 DSLR, Nikon AF Nikkor 24–85mm lens set to 24mm and f/3.2, ISO 1600, one hundred and twenty 35-second exposures, stacked) • ***Bret Dahl***

5. THE LARGE MAGELLANIC CLOUD
The Milky Way's largest satellite covers an area 650' by 550'. No fewer than 114 NGC objects lie within its borders. (Pentax 67 300 f/4 ED IF lens attached to an FLI Proline 16803 CCD camera, four-panel mosaic, Hα/OIII/LRGB image with exposures of 1,200, 820, 960, 470, 480, and 490 minutes, respectively) • ***Marco Lorenzi***



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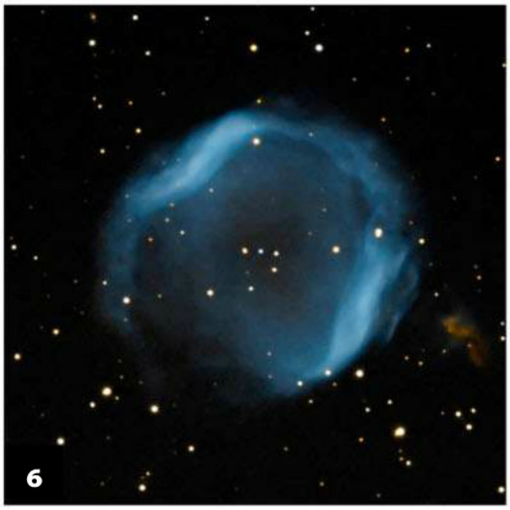

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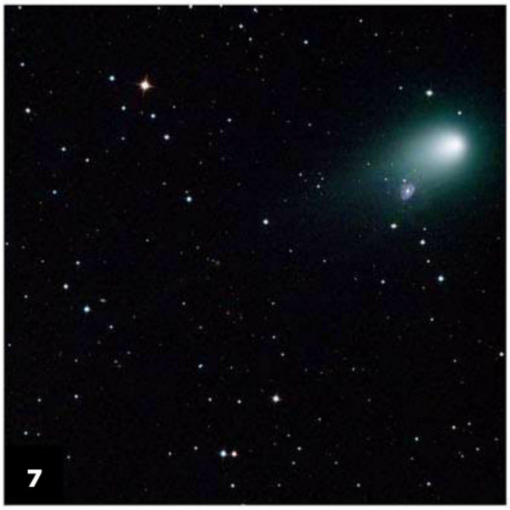

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6. JONES 1
PK 104–29.1 is a planetary nebula discovered photographically by Rebecca Jones at Harvard University in 1941. At magnitude 12.7 and with a low surface brightness, it's a difficult object to snag visually. (24-inch RC Optical Systems Ritchey-Chrétien reflector, SBIG STX-16803 CCD camera, Hα/OIII image with exposures of 500 and 460 minutes, respectively) • ***Mark Manner***

7. 168P/HERGENROTHER
This periodic comet passed in front of the magnitude 14.8 spiral galaxy PGC 250 in early October. (32-inch Schulman Telescope, SBIG STX-16803 CCD camera, RGB image with 9-minute exposures through each filter, taken October 5, 2012) • ***Adam Block/Mount Lemmon SkyCenter/University of Arizona***

8. THE CAT'S PAW NEBULA
NGC 6334 in Scorpius looks different in this image, which incorporates narrow-band exposures, from what you'd see at an eyepiece. NGC 6334 ranks among the Milky Way's largest star-forming regions. (4-inch Takahashi FSQ-106N apochromatic refractor at f/5, SBIG ST-10XME CCD camera, Hα/OIII/SII/RGB image with exposures of 120, 135, 135, 25, 25, and 25 minutes, respectively) • ***Michael Caligiuri***

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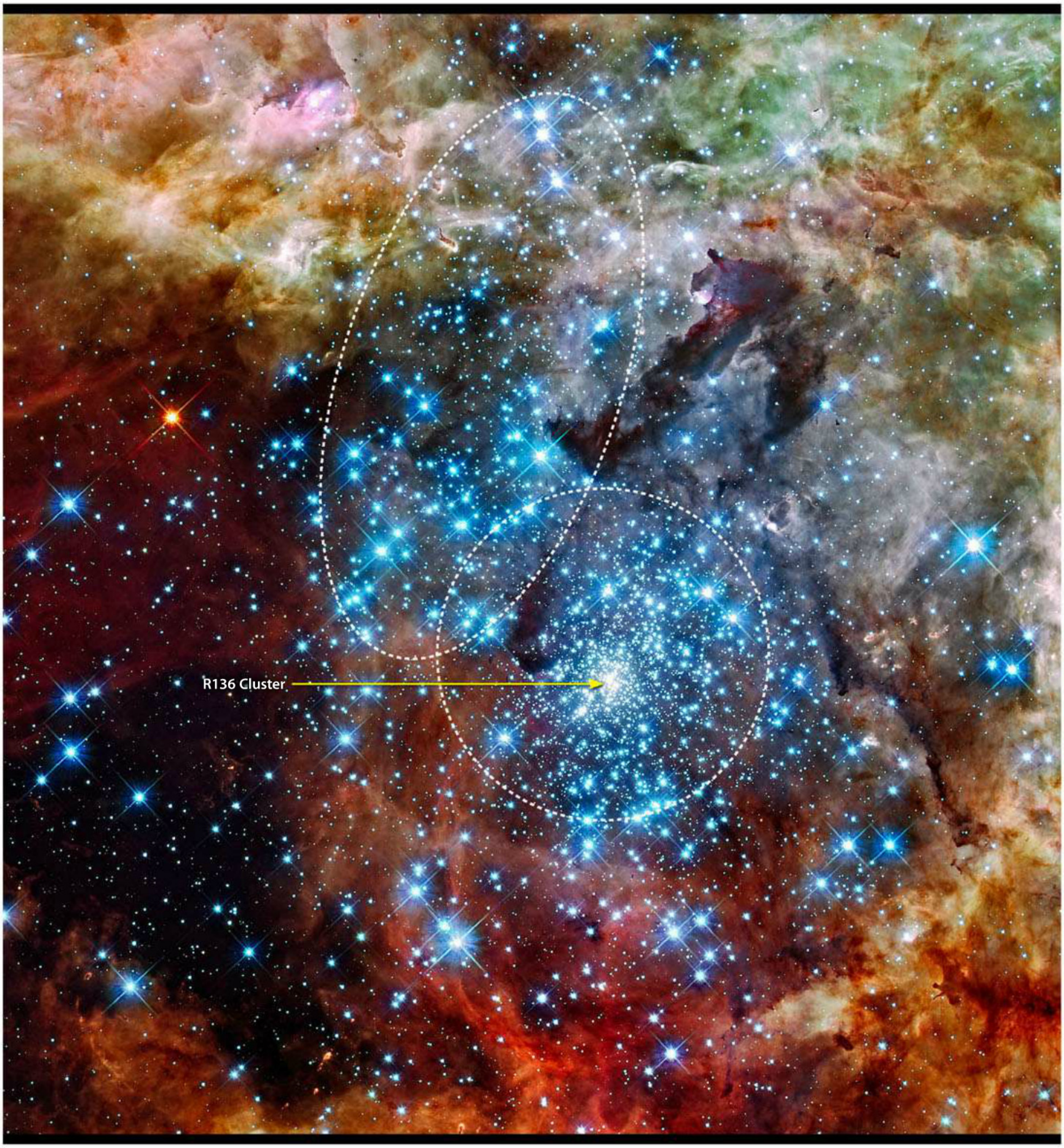

NASA/ESA/E. SABBI (ESA/STSCI)

A close encounter of star clusters

Two star clusters dominate the center of this new Hubble Space Telescope image showing a piece of the Large Magellanic Cloud (LMC), one of two satellite galaxies of the Milky Way. Researchers previously thought that R136, the big cluster at center, produced all the stars in the area. Instead, a second cluster (oval, left of center) contains high-speed stars moving toward R136 and most likely will merge with it.

This region of gas in the LMC is called the Tarantula Nebula, and it's been churning gas and dust into stars for at least 25 million years. Such clusters provide the opportunity to look into vast stellar nurseries.

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Astronomy's 2013 Guide to the Night Sky

LUNAR PHASES

New	First	Full	Last
			Jan. 4
Jan. 11	Jan. 18	Jan. 26	Feb. 3
Feb. 10	Feb. 17	Feb. 25	March 4
March 11	March 19	March 27	April 3
April 10	April 18	April 25	May 2
May 9	May 18	May 25	May 31
June 8	June 16	June 23	June 30
July 8	July 15	July 22	July 29
Aug. 6	Aug. 14	Aug. 20	Aug. 28
Sept. 5	Sept. 12	Sept. 19	Sept. 26
Oct. 4	Oct. 11	Oct. 18	Oct. 26
Nov. 3	Nov. 10	Nov. 17	Nov. 25
Dec. 2	Dec. 9	Dec. 17	Dec. 25

All dates are for the Eastern time zone. A Full Moon rises at sunset and remains visible all night; a New Moon crosses the sky with the Sun and can't be seen.

THE MOON is Earth's nearest neighbor and the only celestial object humans have visited. Because of its changing position relative to the Sun and Earth, the Moon appears to go through phases, from a slender crescent to Full Moon and back. The best time to observe our satellite through a telescope comes a few days on either side of its two quarter phases. For the best detail, look along the terminator — the line separating the sunlit and dark parts. NASA/GSFC/Arizona State University

VENUS begins the year in the morning sky. On January 1, it rises 90 minutes before the Sun and appears like a beacon in the southeast before dawn. After disappearing in the twilight glow during February, the planet returns to view after sunset in May. Late that month, it joins Mercury and Jupiter to create a stunning trio. Venus reaches its 2013 peak in early December, when it shines brightest and appears highest in the southwest as darkness falls. NASA

JUPITER always shows a dynamic face. Its atmosphere displays an alternating series of dark belts and brighter zones pocked by the Great Red Spot. Even through the smallest telescope, the planet's four big moons appear conspicuous. These satellites often move dramatically during the course of a single night. Jupiter dominates the evening sky from January through May, then returns to view on July mornings. By year's end, the planet shines brilliantly (at magnitude –2.7) from dusk to dawn and spans 47". NASA/JPL/USGS

SATURN and its rings provide a spectacular attraction for telescope owners during most of 2013. The ringed world is on display from January until October and again in December, but it appears best around the time of opposition in late April. Saturn then shines at magnitude 0.1 and its disk measures 19" across, while the rings span 43" and tilt 18° to our line of sight. Even a small telescope reveals the dark, broad Cassini Division that separates the outer A ring from the brighter B ring. NASA/ESA/STScI

WINTER

The sky

Winter boasts the brightest stars of any season. Orion the Hunter dominates the evening sky this time of year. Its seven brightest stars form a distinctive hourglass pattern. The bright blue star marking Orion's left foot is Rigel, and the ruddy gem at his right shoulder is Betelgeuse. The three stars of the Hunter's belt point down to Sirius, the brightest star in the night sky, and up to Aldebaran, the eye of Taurus the Bull. To Orion's upper left lies the constellation Gemini.

Deep-sky highlights

The Pleiades (M45) is the brightest star cluster in the sky. It looks like a small dipper, but it is not the Little Dipper.

The Orion Nebula (M42), a region of active star formation, is a showpiece through telescopes of all sizes.

The Rosette Nebula (NGC 2237–9), located 10° east of Betelgeuse, presents an impressive cluster of stars and a nebula.

M35 in Gemini the Twins is a beautiful open cluster best viewed with a telescope.

Castor (Alpha [α] Geminorum) is easy to split into two components with a small telescope, but the system actually consists of six stars.

SPRING

The sky

The Big Dipper, the most conspicuous part of the constellation Ursa Major the Great Bear, now rides high in the sky. Poke a hole in the bottom of the Dipper's bowl, and the water would fall on the back of Leo the Lion. The two stars at the end of the bowl, called the Pointer Stars, lead you directly to Polaris, the North Star. From the bowl's top, simply go five times the distance between the Pointers. Spring is the best time of year to observe a multitude of galaxies. Many of these far-flung island universes, containing hundreds of billions of stars, congregate in northern Virgo and Coma Berenices.

Deep-sky highlights

The Beehive Cluster (M44) was used to forecast weather in antiquity. It is a naked-eye object under a clear, dark sky, but it disappears under less optimal conditions.

M5, a conspicuous globular cluster, lies between the figures of Virgo the Maiden and Serpens Caput the Serpent's Head.

The Whirlpool Galaxy (M51) is a vast spiral about 30 million light-years away.

M81 and **M82** in Ursa Major form a pair of galaxies that can be spotted through a telescope at low power.

Star maps by *Astronomy*: Roen Kelly

2013 EVEN

Jan. 3 Quadran peaks

Feb. 16 Mercur eastern elongati

March 17 The M south of Jupiter

April 25 Partial

April 28 Saturn

May 5 Eta Aqua shower peaks

May 9 Annular (Australia, Papua Pacific Ocean)

May 28 Venus p of Jupiter

June 12 Mercur eastern elongati

July 1 Pluto is a

July 30 Mercury western elongat

Aug. 12 Perseic peaks

Aug. 26 Neptur

Sept. 28 The M south of Jupiter

Oct. 3 Uranus is

Nov. 1 Venus is eastern elongati

Nov. 3 Total sol Ocean, equatori

Nov. 17 Mercur western elongat

Dec. 6 Venus is brilliancy

Open cluster
Globular clus
Diffuse nebu
Planetary ne
Galaxy

TS

tid meteor shower

y is at greatest
on

Moon passes 1.5°

lunar eclipse

is at opposition

rid meteor

solar eclipse
a New Guinea,

passes 1.0° north

ry is at greatest
on

t opposition

y is at greatest
ion

d meteor shower

ne is at opposition

oon passes 5°

s at opposition

at greatest
on

ar eclipse (Atlantic
al Africa)

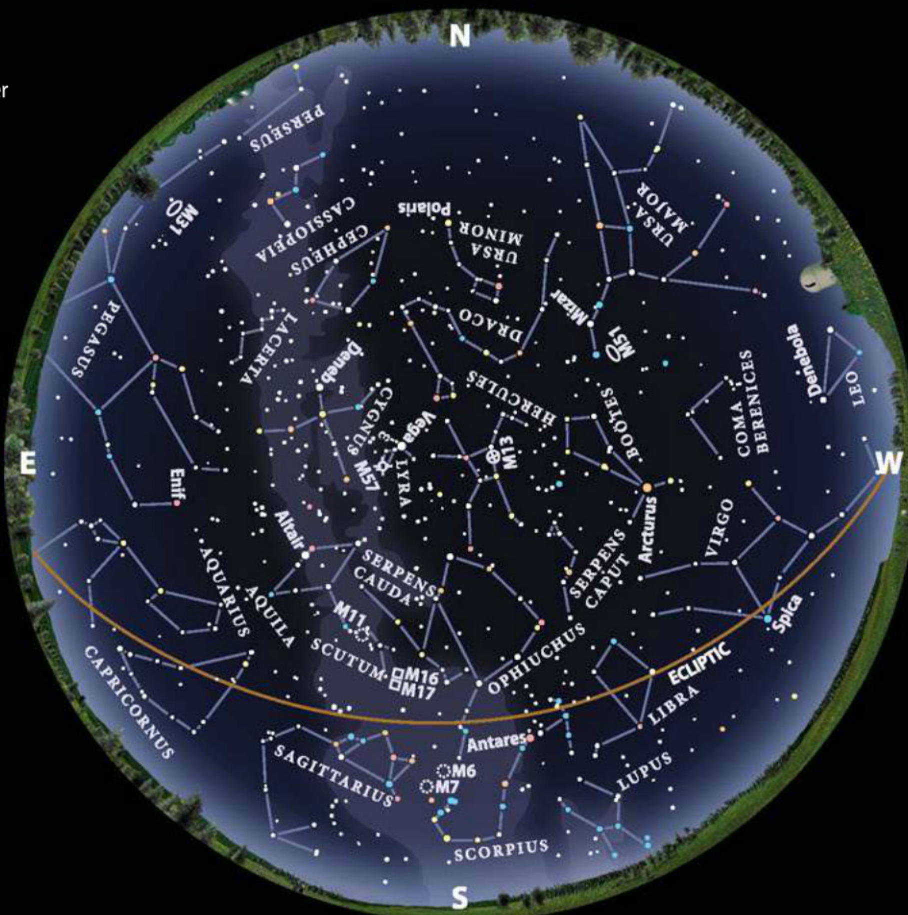
ry is at greatest
ion

at greatest

ter

la

bula



SUMMER

The sky

High in the sky, the three bright stars known as the Summer Triangle are easy to spot. These luminaries — Vega in Lyra, Deneb in Cygnus, and Altair in Aquila — lie near the starry path of the Milky Way. Following the Milky Way south from Aquila, you'll find the center of our galaxy in the constellation Sagittarius the Archer. Here lie countless star clusters and glowing gas clouds. Just west of Sagittarius lies Scorpius the Scorpion, which contains the red supergiant star Antares as well as M6 and M7, two brilliant clusters that look marvelous at low power.

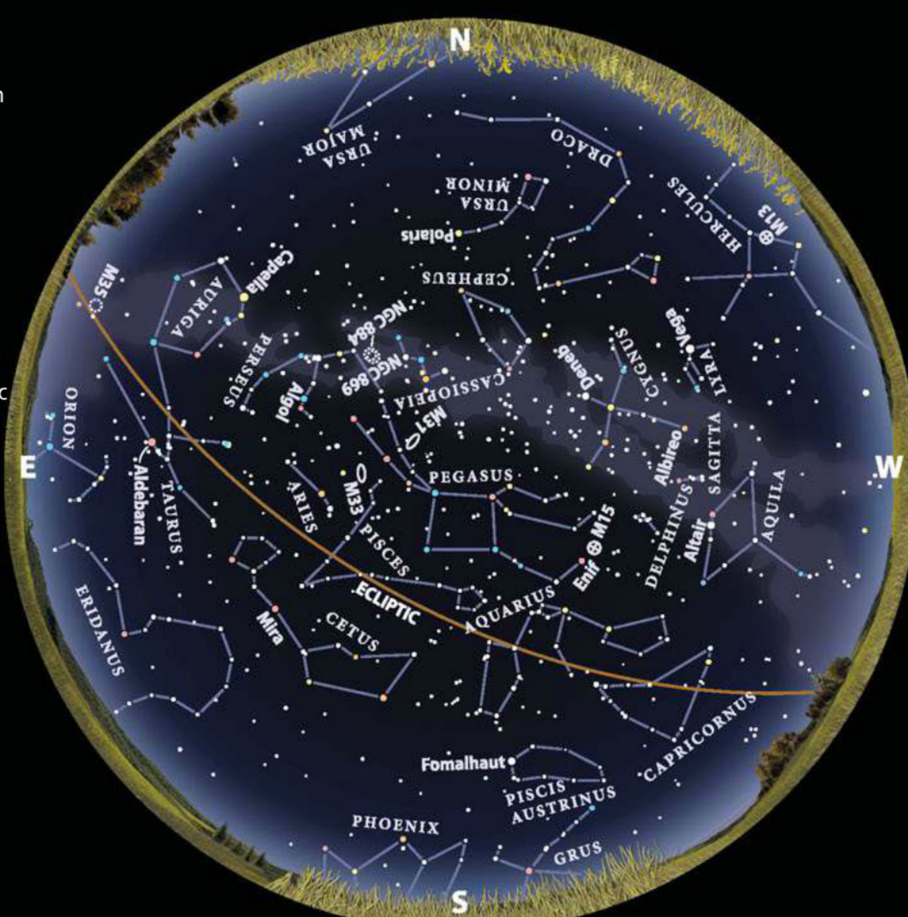
Deep-sky highlights

The Hercules Cluster (M13) contains nearly a million stars and is the finest globular cluster in the northern sky.

The Ring Nebula (M57) looks like a puff of smoke through a medium-sized telescope.

The Omega Nebula (M17) looks like the Greek letter of its name (Ω) through a telescope at low power. This object also is called the Swan Nebula.

The Wild Duck Cluster (M11) is a glorious open star cluster. On a moonless night, a small scope will show you some 50 stars.



AUTUMN

The sky

The Big Dipper swings low this season, and from parts of the southern United States, it even sets. With the coming of cooler nights, Pegasus the Winged Horse rides high in the sky as the rich summer Milky Way descends in the west. Fomalhaut, a solitary bright star, lies low in the south. The magnificent Andromeda Galaxy reaches its peak nearly overhead on autumn evenings, as does the famous Double Cluster. Both of these objects appear as fuzzy patches to the naked eye under a dark sky.

Deep-sky highlights

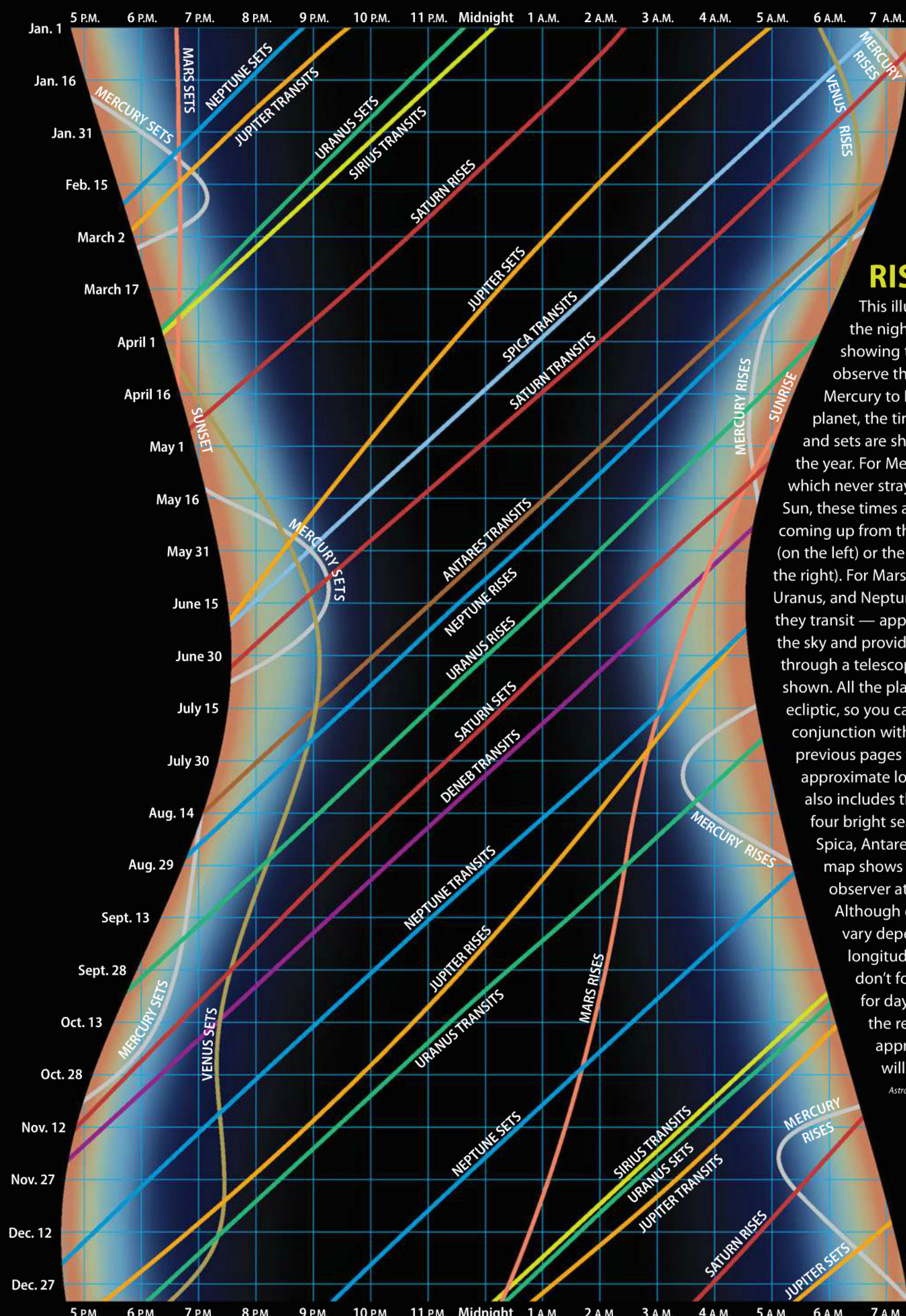
The Andromeda Galaxy (M31) is the brightest naked-eye object outside our galaxy visible in the northern sky.

The Double Cluster (NGC 869 and NGC 884) in Perseus consists of twin open star clusters. It's a great sight through binoculars.

M15 in Pegasus is a globular cluster containing hundreds of thousands of stars, many of which can be glimpsed through a medium-sized telescope.

Albireo (Beta [β] Cygni), the most beautiful double star in the sky, is made up of suns colored sapphire and gold.

Astronomy magazine



RISE & SET

This illustration presents the night sky for 2013, showing the best times to observe the planets from Mercury to Neptune. For each planet, the times when it rises and sets are shown throughout the year. For Mercury and Venus, which never stray too far from the Sun, these times appear as loops coming up from the sunset horizon (on the left) or the sunrise horizon (on the right). For Mars, Jupiter, Saturn, Uranus, and Neptune, the times when they transit — appear highest in the sky and provide the best view through a telescope — also are shown. All the planets lie near the ecliptic, so you can use this chart in conjunction with the maps on the previous pages to find a planet's approximate location. The chart also includes the transit times of four bright seasonal stars: Sirius, Spica, Antares, and Deneb. This map shows local times for an observer at 40° north latitude. Although exact times will vary depending on your longitude and latitude (and don't forget to add an hour for daylight saving time), the relative times and approximate positions will stay the same.

Astronomy: Rick Johnson

MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

March 2013: Mercury at its best

As darkness falls in March, only one bright planet is on display. **Jupiter** dominates the northwestern sky, outshining the otherwise conspicuous background stars of Taurus the Bull. Shining at magnitude –2.2, the giant planet bests the Bull's luminary, 1st-magnitude Aldebaran, by some 20 times. Jupiter moves slowly eastward this month and passes 5° north of Aldebaran on March 24.

The gas giant appears about 25° high in the fading twilight at midmonth, still plenty high enough to deliver good views through a telescope. Notice how the planet bulges in the middle, with its equatorial diameter (37") exceeding its polar diameter by 2.4". Also watch for an alternating series of dark belts and lighter zones that runs parallel to the planet's equator. Above the cloud tops, Jupiter's four bright moons execute a finely choreographed dance. On March 17 and 18, a waxing crescent Moon appears near the planet.

Later in the evening, **Saturn** rises in the east. The ringed planet lies among the relatively dim stars of western Libra, just north of an imaginary line connecting Spica in Virgo and Antares in Scorpius. At magnitude 0.3, the planet shines noticeably brighter than either star.

For the best views of Saturn through a telescope, wait until it climbs higher in the sky by late evening or after midnight. The higher altitude improves your chances of good seeing conditions because the object's light then passes through less of Earth's turbulent atmosphere. Saturn looks spectacular, with its 18"-diameter disk encircled by a ring system that spans 41" and tilts 19° to our line of sight. You can see the globe, the rings, and the planet's brightest moon, 8th-magnitude Titan, through telescopes of all sizes.

Although **Mercury** passes between the Sun and Earth on March 4, the innermost planet quickly climbs into view in the eastern sky before dawn. It reaches greatest elongation March 31, when it lies 28° west of the Sun. It then rises more than two hours before our star and stands 15° high an hour before sunrise.

As the planet draws away from the Sun, its size slowly decreases while its phase rapidly increases. A small telescope easily reveals these changes toward the end of the month. On March 20, for example, Mercury appears 9.3" across with a 28-percent-lit phase. By the 31st, it shows a half-lit disk that measures 7.7" across.

Earth's two neighboring planets, Venus and Mars, remain hidden in the Sun's glare throughout March. **Venus** reaches superior conjunction — when it lies on the opposite side of the Sun as seen from Earth — March 28. **Mars** will be in solar conjunction April 18.

The Moon occults Spica twice this month. On March 1, a waning gibbous Moon occults the star for observers in parts of central South America. From Santiago, Chile, Spica disappears at 7h19m UT and reappears at 7h36m UT. On March 28, residents in much of the East Indies and northern and northeastern Australia will see a nearly Full Moon block the star. From Manila, Philippines, Spica disappears at 12h50m UT and reappears at 13h53m UT.

The starry sky

As darkness falls during March, Orion the Hunter remains a fine sight in the northwestern sky. One of the striking features of this magnificent constellation is its pair of bright stars: Rigel (Beta [β] Orionis) and Betelgeuse (Alpha [α] Orionis).

Blue-white Rigel stands at the upper left of the constellation and marks the position of the Hunter's left foot as he faces us. The star's name comes from the Arabic *rijl*, which means "foot." Draw an imaginary line from Rigel though Orion's Belt and you'll come to ruddy Betelgeuse. Often mispronounced BEET-el-jooz, its correct pronunciation is BET-el-jooz. Historians think this name originated as *yad al-jauza*, meaning "hand of the giant," but it appears to be a miscopy of the phrase *ibt al-jauza*, meaning "armpit of the giant."

Astronomers classify both stars as supergiants, but their colors tell us they are different beasts. Rigel has a mass close to 18 times that of the Sun. Only about 10 million years old, it eventually will expand to become a red supergiant. Scientists have little doubt that Rigel will become a supernova once it exhausts the nuclear fuel in its core. When it explodes, the star will appear 100 times brighter than Venus in our sky.

Betelgeuse has around the same mass as Rigel, if not a little more. The main difference between the two is that the former has evolved more and finds itself as a red supergiant. Its reddish color stems from a lower surface temperature — Betelgeuse glows at around 3650 kelvins while Rigel blazes at approximately 11,500 kelvins.

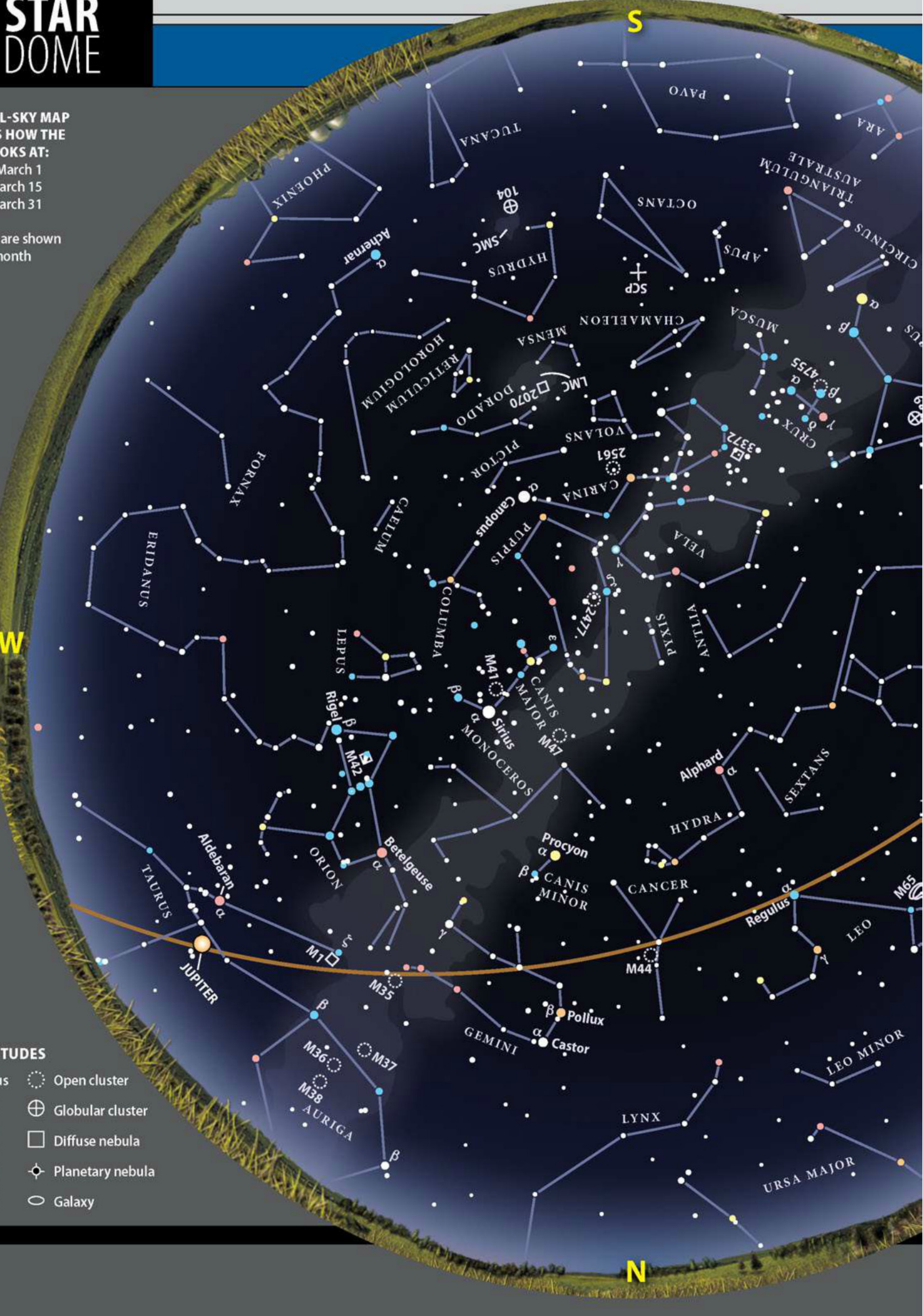
Astronomers have measured Rigel's diameter to be 73 times that of the Sun. If it were placed at the center of our solar system, its outer layers would stretch nearly to Mercury's orbit. Betelgeuse is considerably larger, however. This was the first star beyond the Sun where astronomers were able to measure its angular diameter. It spans a meager 0.047" in our sky, but that translates into a star whose surface would extend nearly to the orbit of Jupiter if it took the Sun's place.

The large masses of both stars mean they are excellent candidates to become supernovae. Think about this as you gaze at Orion's left foot and right armpit these March evenings. And imagine how Orion will look when one of these stars explodes and becomes the brightest point of light in our night sky.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
10 P.M. March 1
9 P.M. March 15
8 P.M. March 31

Planets are shown at midmonth



MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0
- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

HOW TO USE THIS MAP: This map portrays the sky as seen near 30° south latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

STAR COLORS: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white unless magnified.

Illustrations by *Astronomy*: Roen Kelly

MARCH 2013

Calendar of events

1 The Moon passes 0.1° south of Spica, 7h UT

2 The Moon passes 3° south of Saturn, 15h UT

4 Mercury is in inferior conjunction, 13h UT

Last Quarter Moon occurs at 21h53m UT

5 The Moon is at perigee (369,957 kilometers from Earth), 23h19m UT

10 The Moon passes 6° north of Neptune, 16h UT

11 New Moon occurs at 19h51m UT

16 Mercury is stationary, 21h UT

17 Asteroid Eunomia is at opposition, 1h UT

18 The Moon passes 1.5° south of Jupiter, 1h UT

19 The Moon is at apogee (404,261 kilometers from Earth), 3h13m UT

First Quarter Moon occurs at 17h27m UT

20 March equinox occurs at 11h02m UT

24 Jupiter passes 5° north of Aldebaran, 18h UT

27 Full Moon occurs at 9h27m UT

28 The Moon passes 0.005° north of Spica, 15h UT

Venus is in superior conjunction, 17h UT

29 Uranus is in conjunction with the Sun, 1h UT

The Moon passes 3° south of Saturn, 20h UT

31 The Moon is at perigee (367,504 kilometers from Earth), 3h51m UT

Mercury is at greatest western elongation (28°), 22h UT